[Inset, to precede p. 1, Nov. 1941 Journal.

JOURNAL OF THE INSTITUTION OF CIVIL ENGINEERS.

No. 1. 1941–42.
NOVEMBER 1941.

ORDINARY MEETING.

4 November, 1941.

Sir LEOPOLD HALLIDAY SAVILE, K.C.B., the retiring President, in the Chair.

Sir Leopold Savile said he knew it was with deep regret that the members of The Institution had heard of the deaths, during the recess, of Mr. Cecil Lee Howard Humphreys, Member of Council, and of Lord Cadman, of Silverdale, and Mr. Maurice Deacon, former Members of Council.

Resolutions of condolence had been passed by the Council, and had been sent to their respective families.

The Council reported that they had recently transferred to the class of

Members.

Arthur James Adams, M.Sc. (*Birmingham*).
Harry Brompton, B.Sc. (Eng.) (*Lond.*).
Horace Cardwell Day.
Randolph Edward Docwra.
Henry William Flett.
Eric John Lawson Gibson, B.A. (*Stanford, Cal.*).
Donald William Gollan.
Douglas Harold Green, O.B.E., M.C., B.Sc. (Eng.) (*Lond.*).
Robert Hugh Stannus Howell, B.Sc. (Eng.) (*Lond.*).
James Macfadzean, B.Sc. (*Glas.*).
John Murdoch Main, B.E. (*Sydney*).
William Langston Newnham.
Jack Vickerman Oldfield, M.B.E.
Savile Packshaw, B.Sc. (Eng.) (*Lond.*).
Frank Alan Rayfield.
John Reginald Roberts.
William Meilir Lloyd Roberts, M.Eng. (*Liverpool*).
James Semple.
Henry Walter Stevens, B.Sc. (Eng.) (*Lond.*).
Arthur Ayton Symington, B.Sc. (Eng.) (*Lond.*).
Lewie Dewar Walker.
William Roy Watson, B.Sc. (Eng.) (*Lond.*).
Robert Meredydd Wynne-Edwards, D.S.O., M.C., M.A. (*Oxon.*).

And had admitted as

Students.

Samuel Louis Abbott.
Robert William Acheson-Gray.
John Renwick Kay Adams, B.Sc. (Eng.) (*Lond.*).
Peter James Adams.
Reginald Walter Adams, B.Sc. (*Birmingham*).
John Allen, B.A. (*Cantab.*).
John Ratter Anderson, Jun.
William Henry Andrews.
John Arthur Stanley Annatt.
Joseph Frederick Armstrong.
Thomas Neill Arnold.
Willie Atha, Jun.

Lawrence Bailey.
John Charles Laing Balmer.
Roger William Barber.
Arthur Inverdale Barry.
Ronald Kirkwood Bates.
Roy Warren Beard.
Victor John Belman, B.Sc. (*Birmingham*).
Thomas Cambell Beswick.
Reginald Bidgood.
Denzil Barry Borg.
Charles William Bosher.
Robert Owen Bradbury.
Derek Taylor Bradshaw.
Thomas Arthur George Bristow.
Iain Macrae Buchan.
George Bunting.
Raymond Wilton Burrell.
Ronald Carlile Buxton.
William Lyndon Byrne.
Richard Ernest Calvert.
Alan Donald Bruce Cameron, B.Sc. (*Cape Town*).
Ian Cameron Campbell.
Ian Macdonald Campbell.
Jeyaratnam Canagaratham.
Brian Turnbull Clarke.
Warwick Victor Clay.
Henry Michael Greig Cockbain.
Arthur Cooke.
Francis Atkinson Cook.
William David Coombs.
Stephen Thorp Cooper.
John Ernest Crofts.
Norbert Patrick Crook.
Leonard Addison Dalton.
Peter Anthony Davies.
Robert Eric Dawson.
John Bernard Atkinson Day.
Norman Wilfred Durrant.
Thomas David Eaton, B.Sc. (Eng.) (*Lond.*).
David Granville Edge.
James Gordon Edmond.
Eric Leonard Eggins.
Harvey Evans.
Kenneth Fenton.
Albert Gordon Glaze.
Robert Goldie.
Norman Lindsay Good.
Brian Garner Goodier.
John Edward Gosney.
William Douglas Goulden.
Eric William Hunter Greig.
Stanley Basnett Grocott.
Vivian Charles Gurney.
Gordon Cansdell Hicks.
Eric Leonard Holmes.
Charles William Holt.
Cuthbert Roger Chegwiddon Howard.
Stanley Peerman Hutton.
Louis Jenner.
Geoffrey Derrick Johnson.
Alexander Irving Johnstone.
Daniel Morgan Phillips Jones.
Theodore Michael Prosser Jones.
Trevor Prytherch Jones.
Arthur Colin Kain, B.Sc. (*Cape Town*).
Joseph Wilfrid Keogh.
John Frederick Knight.
Arumadura Nandasena Silva Kulasinghe.
Cecil John Lang.
Kenneth Law.
Francis Lawrence.
Derrick Lee, B.Sc. (Eng.) (*Lond.*).
Kenneth Dewes Lewis.
George Gordon Lilley, B.A. (*Cantab.*).
Norman Thomas Long.
Stuart Pratt Low.
Cedric John Lucas.
Kenneth Edmund Lusty.
John James McCarry, B.E. (*National*).
Henry McClusky.
James McClusky.
Matthew Aiken McIlgorm.
James McInnes.
Dugald Blair McIntyre.
James McLean.
Alexander John McMinn.
James McNair.
Stanley Gordon Marshall, B.A. (*Cantab.*)
Frederick Royal Martin, B.Sc. (*Birmingham*).
Vernon Maslin.
Victor Thomas William Mason.
Eric Douglas Mellor.
Robert Mitchell-Lanman.
Stuart Redpath Mollison.
Michael Angelo Morelli.
Vincent Leslie Mullowney.
Alan Cameron Murray.
William James Suttie Murray.
Harvey Jenkin Mutch.
Norman John Nicholls.
Jack Tyson Norburn.
Albert Michael Horner Norris.
Horace Roy Oakley.
Nahum Noel Beryl Ordman, B.Sc. (*Edin.*).
James Nichol Osborne.
James Harsant Page, B.A. (*Cantab.*).
Maurice Gladwyn Victor Paine.
Stewart Henry Pattinson.
Timothy Winthrop Pellew, B.A. (*Cantab.*).
Anthony William Pennock.
Frederick John Perera.
Kollurage Piyadasa Perera.
James Windsor Pritchard.
Gordon Bayard Ralph.
Kenneth John Reading.
Mohammad Rehman, B.Sc. (*Delhi*).

Michael Richardson.
John Alexander Robb, B.Sc. (*Bristol*).
Leon Robinson.
Christoffel Johannes Willem Ross.
Charles Ernest Rowand.
Sivakuru Sanmuganathan.
Maurice Robert Humphrey Shippey.
Angus McInnes Smart.
Geoffrey Howard Smith.
Geoffrey John Smith.
Stanley William Smith.
Michael Frederick Alfred Snell.
Robert Oscar Summers.
Harry Sutcliffe.
John Miller Tainsh.
John Charles Newman Theobald.
Robert Burns Thomson.
Roland Wilson Thornton, B.Eng. (*Liverpool*).
Charles Alexander Thwaites.
Peter Harland Totty, B.Sc. (Eng.) (*Lond.*).
Peter Cedric Hyde-Trutch.
George Ernest Tuck.
Sidney Turley, B.Sc. (*Birmingham*).
James Addin Tyldesley.
John Francis Underwood.
Robert William Vollar.
Hubert John Wadsworth.
Robert Holland Walpole.
John Edward Ward.
Charles Ingram Watson.
Temple Kelsey Webb.
Frederick Westall, B.A. (*Cantab.*).
Charles Allan Wheatley.
Arthur Douglas Whittaker.
Thomas George Martin Wickens.
Clifton Albert Stanley Wilde.
Ronald Henry Charles Wilks.
Henry Borthwick Wilson.
Roy Arthur Wood.
Joseph Algernon Yorke.

The Scrutineers reported that the following had been duly elected as

Members.

Geoffrey Murton Gill.
Fred Bernard, Kerridge.
Sir Alexander Macdonald Rouse, C.I.E., F.C.H.

Associate Members.

Peter Lawrie Aitken, B.Sc. (*St. Andrews*), Stud. Inst. C.E.
Frederic Pasley Alban, B.Sc. (Eng.) (*Lond.*).
Guy Dunn Allison, B.Sc. (*Durham*), Stud. Inst. C.E.
John Edward Henry Anderson, Stud. Inst. C.E.
William Henry Appleyard, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
Gilbert John Barrington, Stud. Inst. C.E.
Jack Beetham, B.Sc. (*Manchester*).
Geoffrey Wardle Bell, M.C., B.Sc. (*Durham*).
John Michael Birdsell, M.Eng. (*Sheffield*), Stud. Inst. C.E.
Geoffrey Boardman, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
Merville Harry Britten, Stud. Inst. C.E.
Frank Edward Bruce, M.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
Richard Colville Burton.
Ross Campbell, Stud. Inst. C.E.
Norman Dobson Carter, B.Eng. (*Liverpool*), Stud. Inst. C.E.
William John Charlton, B.Sc. (*Leeds*).
James Leith Clark, Stud. Inst. C.E.
Vernon George De Sevigne Coleman, B.Sc. (*New Zealand*).
Cyril Austen Collins, Stud. Inst. C.E.
Basil Glover Combridge, Stud. Inst. C.E.
Alfred Eric Ridgway Cope.
Joseph Cowan, Stud. Inst. C.E.
Ian Gordon Croxford, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
William Lightbody Dale.
Arnold Haydn Davies, B.Sc. (*Wales*).
Cyril Hewetson Davison, Stud. Inst. C.E.
Harold Stanhope Day, B.Eng. (*Liverpool*), Stud. Inst. C.E.
Gadadhar De, B.Sc. (*Bristol*).
Kenneth John Evans, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
Robert James Evans, B.Sc. Tech. (*Manchester*), Stud. Inst. C.E.
Hugh Duncan Findlay, B.Sc. (*Glas.*), Stud. Inst. C.E.
Arthur Fisher.
William Stewart Forbes, B.Sc. (*Edin.*), Stud. Inst. C.E.
William Lees Foster, B.Sc. (*St. Andrews*), Stud. C.E.
Alfred John Louis Gamper, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
James Nicholson Garden, Stud. Inst. C.E.
James Clifford Garnett, Stud. Inst. C.E.

Peter Alfred Greenway, B.Sc. (Eng.) (*Lond.*).
Ivan Sydney Stroulger Greeves, Stud. Inst. C.E.
Ernest Reginald Griffiths, Stud. Inst. C.E.
Frederick John Hale.
Gilbert Claude Harvell, Stud. Inst. C.E.
Frederick Denis Cameron Henry, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
Gilbert John Hoad.
John Robert Houghton, Stud. Inst. C.E.
Laurence Leslie Huss.
Bangalore Varadiyengar Seetharama Iyengar, B.Sc. (Eng.) (*Lond.*).
Howard Elias Jones, B.Eng. (*Liverpool*).
Leslie James Kastner, M.A. (*Cantab.*), M.Sc. (*Manchester*).
Alexander Milroy Kennedy, Jun., B.A. (*Cantab.*), Stud. Inst. C.E.
John Charles Landon, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
Ernest Wilson Latham, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
Charles Leng.
Kenneth Campbell McCrae, Stud. Inst. C.E.
Archibald McDougall, B.Sc. (*Edin*), Stud. Inst. C.E.
Charles Gerald McNamara, B.E. (*National*).
Robert Stuart McNeill, Stud. Inst. C.E.
Andrew Macartney Malcolm, M.A. (*Edin.*).
Albert Desmond Hutchinson Martin, B.A.I. (*Dubl.*), Stud. Inst. C.E.
Alexander Millar.
Sidney Myer Myers, B.Sc. (Eng.) (*Lond.*).
Gilbert Frank Norris, Stud. Inst. C.E.
William Thomas Oliver, B.Sc. (*Durham*).
Michael Joseph O'Sullivan, B.E., B.Sc. (*National*).
Elrington Robert Lennard O'Toole, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
William Hugh Owen.
Basil Harold Pattinson, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
Walter George Prow, Stud. Inst. C.E.
John Herbert Quayle.
Arnold John Richmond, B.Sc. (*S. Africa*), Stud. Inst. C.E.
Arthur John Edward Ridley.
Cyril Rigby, Stud. Inst. C.E.
Wilfred John Rittman.
Frederick Louis Robinson, B.Sc. (Eng.) (*Lond.*), Stud. Inst. C.E.
John Riseley Robinson.
Oliver Cyril Rowe.
Walter Richard Rowland.
Frederick Raymond Salkeld, Stud. Inst. C.E.
Arthur Shallcross, Stud. Inst. C.E.
Harrison Simpson, B.Sc. (Eng.) *Lond.*).
Cyprian Mitford Slocombe.
Jack Bromley Stapley, Stud. Inst. C.E.
Harry Cresswell Steeples.
John Stewardson, Stud. Inst. C.E.
Alastair Storrar, B.Sc. (*Edin.*), Stud. Inst. C.E.
Nilkanth Ramchandra Tembe, M.Sc. (Eng.) (*Lond.*), B.E. (*Bombay*), Stud. Inst. C.E.
John Thompson, Stud. Inst. C.E.
John Leslie Timbers, Stud. Inst. C.E.
John Leslie Unitt, Stud. Inst. C.E.
John Francis Varcoe, B.Sc. (*Birmingham*), Stud. Inst. C.E.
Edward Charles Vaughan, Stud. Inst. C.E.
John Philip Wain, Stud. Inst. C.E.
Ronald Leslie Walshe, B.Sc. (*Belfast*), Stud. Inst. C.E.
Frederick Maurice Watts.
John Edmund Gifford Whittome, Stud. Inst. C.E.
Geoffrey Wimpenny, B.Sc. (*Leeds*), Stud. Inst. C.E.
Randal Herbert Wood, B.Sc., Ph.D. (*Leeds*).
Stanley Whyte Wood, B.Sc. (*Aberdeen*), Stud. Inst. C.E.

Associates.

Roland Thomas Pemberton.
Stewart Salmond.

The retiring President said that the final act of his year of office was to introduce the new President, and this he did with the greatest pleasure, as Professor Inglis was a very good friend of his—in fact, they had been pupils together with Sir John Wolfe Barry and Brunel many years ago, and Professor Inglis was now the third of those pupils to become President

of The Institution; all knew of his eminence as an engineer and as Professor of Engineering at Cambridge University, where he had been responsible for the training of—Sir Leopold would not like to say how many—budding engineers.

Professor CHARLES EDWARD INGLIS, O.B.E., M.A., LL.D., F.R.S., President, having taken the Chair,

Mr. S. B. DONKIN, Past-President, proposed a vote of thanks to the retiring President. He said he was sure everyone would agree that, throughout his year of office, the work Sir Leopold had done had been extraordinarily assiduous, careful, and satisfactory, and his kindly and generous nature had helped to make the work of the Council—and, indeed, of The Institution generally—successful. The duties undertaken by Sir Leopold might have seemed easy to some; but actually, on account of the war and of consequent changes in the various programmes of The Institution, they had been extremely difficult, and such complications had been one of the more trying tasks with which he had had to contend. He had borne these responsibilities with good will and, Mr. Donkin considered, with great fortitude. Like most men with Admiralty experience and a connexion with the Royal Navy, Sir Leopold had been able to endure those responsibilities with a smile and with courage. It was with the greatest pleasure, therefore, that he formally proposed a vote of thanks to Sir Leopold for the services he had rendered to The Institution during his term of office as President.

Mr. W. J. E. BINNIE, Past-President, seconded the motion, which was carried by acclamation.

Sir LEOPOLD SAVILE, in acknowledging the resolution, expressed his gratitude for the very appreciative vote of thanks, though with great diffidence, as he felt it was far more than he deserved. He knew that members would not expect him to make a speech, either to justify what he had done or to excuse himself for what he had not done, but he would like to say that he had received the greatest possible assistance from the Council and from any others whom he had asked for help in his need, and last but not least from the Secretary.

The President then delivered his Presidential Address.

Sir CLEMENT HINDLEY, Past-President, proposed a vote of thanks to Professor Inglis for his address, and said he would like to add a few remarks to try to express what all must feel about the very inspiring discourse that Professor Inglis had been good enough to give them. As the President had reminded them, it was 30 years since The Institution had had an Address

which dealt with the subject of engineering education, and at the present time there was probably more need of guidance in that respect than at any time in The Institution's history. It was important to remember that The Institution had had a very great influence upon engineering education in universities, and it was of the most profound importance that it should exercise all possible authority in the fight towards the strengthening of such education; that was why it was so valuable to have had the whole position reviewed by a past-master of that work at this juncture, and to have had the requirements and the really vital elements of engineering education re-stated in a modern form related to the present difficult times.

Sir Clement said he would not attempt to make any comment upon the really beautiful work of art to which they had listened, but would move that the best thanks of The Institution be accorded to the President for his Address and that he be asked permission for it to be printed in the Journal.

Dr. W. L. Lowe-Brown seconded the resolution, which was put to the meeting and carried by acclamation.

The President expressed his appreciation of the vote of thanks and of the very generous way in which his Address had been received. It was a great pleasure to talk to an audience who seemed so sympathetic with what he had had to say, and he had much pleasure in allowing it to be printed.

The President presented the Baker Gold Medal for the triennial period 1938–1941 to Dr. Oscar Faber, O.B.E., D.C.L., D.Sc., M. Inst. C.E., for his Paper on "Aesthetics of Engineering Structures"†, stating that it gave him great pleasure to make that presentation. It was generally known that the award was one of the highest distinctions which The Institution could confer, and he felt sure anyone who had read the Paper realized it was only a fitting tribute that the Author should receive this Medal.

He considered that the Paper probably instituted a movement which would gather momentum with the passage of time, and might even take people back to the ideals of the old engineers, with their inborn love for beauty of form and pride in the aesthetic merits of engineering works of construction. For returning along those paths, engineers owed Dr. Faber a debt of gratitude, and it was, therefore, a great pleasure to present the Medal to him.

The meeting then closed.

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† Journal Inst. C.E., vol. 16 (1940–41), p. 139 (April 1941).

PROFESSOR CHARLES EDWARD INGLIS, O.B.E., M.A., LL.D., F.R.S.

ELECTED PRESIDENT 1941

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PRESIDENTIAL ADDRESS OF

PROFESSOR CHARLES EDWARD INGLIS, O.B.E, M.A., LL.D., F.R.S.

PRESIDENT, 1941–42.

I DESIRE, in the first instance, to testify my deep appreciation of the honour in becoming President of the Institution of Civil Engineers. It is a position which justifies feelings of pride, but it likewise carries with it a vivid and sobering sense of heavy responsibility. I intend to spare no effort in shouldering this honourable burden, and I shall strive to maintain the high tradition of Presidential devotion to duty, set by my predecessors, with all the energy I possess, and with all the ability which Nature in one of her moods of strict economy saw fit to provide.

It is customary for a President, in his inaugural address, to deal with that specific branch of Engineering about which he possesses first-hand knowledge. Consequently I propose to set forth my views on some aspects of engineering education, more particularly University engineering education, which has been my primary preoccupation for the past forty years. It is many years since the Institution last had an educationalist for its President, and for a precedent to my case it is necessary to go back to the year 1911, when Dr. Unwin was installed. It is easy to account for this wide spacing, since in the past engineering education was given little scope for establishing contact with the outside world. Teachers had few opportunities of practising what they preached, and in respect to the realities of engineering enterprise and progress most of them lived a life of almost monastic seclusion. With industry in Great Britain becoming increasingly research-minded, this state of isolation is rapidly disappearing; but it is only recently that teaching or research in an engineering school has ceased to be an almost insuperable barrier blocking the pathway to corporate membership of the Institution. A more enlightened spirit now prevails; more and more, industry is seeking guidance from academic engineers and utilizing the research laboratories at the Universities and

Technical Schools to solve problems of urgent practical importance. Consequently, in these days, if a young engineer decides to take up an academic career, he does not of necessity cease to be a practical engineer; he can still be of direct and immediate use wherever engineering progress is taking place, indeed he finds himself most favourably situated in the forefront of the fight. That his services should thus be kept available is of real importance to the profession, since an academic career nowadays attracts an increasing number of the ablest engineering recruits. Competition for such positions is so keen that only applicants of outstanding ability and character are successful and, no matter how true it may have been in the past, it is now erroneous to imagine that the rising generation of engineering teachers is being drawn from those who, in the field of practical engineering, have been tried and found wanting. Many of these able young recruits, their light no longer hidden under a bushel, will later on inevitably make their mark; and that is why I venture to predict that in the future to have as your President an engineer whose qualifications are mainly academic, will not be regarded as an anomaly calling for explanation or apology.

I am glad to take this opportunity of voicing some opinions on engineering education, and to do so under conditions where, like a preacher in the pulpit, the most provocative heresies can be pronounced without fear of interruption. For ideas on engineering education can be very provocative and, whereas education for most of the professions is generally accepted with resignation, the training of an engineer is an unending and chronic subject of controversy which is always so near the boiling-point that unless provision for relieving pent-up pressure is periodically provided explosions are likely to occur. With this relief in view, The Institution organized a conference on engineering education, which was to have been held in March 1940, but, like so many of our activities, had to be cancelled. For that occasion I had been invited to give an address on the University Education of engineers; and, now that the chance has recurred, I propose to inflict on you some of the conclusions I have reached as the result of many years of teaching experience involving much trial and error; abundance of trial and probably still more error.

At the outset let me say that my conception of the primary duty of a University is that it should cater for the needs of those who, without any suggestion of class distinction, are expected to become the future officers in the army of civilian engineers—men who are destined ultimately to hold positions of high and varied responsibility. To fulfil this duty education in the broadest and most liberal interpretation of the term is required. On the other hand, the main preoccupation of technical schools should be to give the specialized training so essential for those who in that army will occupy the no less important and far more numerous positions of non-commissioned officers. These two tasks differ fundamentally in technique and although they overlap to some extent, any attempt to reduce them to a common denomi-

nator can only result in an unsatisfactory compromise. Education rather than specialized training should be the University ideal, and in this connexion it cannot be too strongly emphasized that education is something much wider and more profound than mere instruction. Just as culture and civilization are not synonymous terms, so instruction must not be confused with education. Instruction is certainly one of its ingredients, but an overdose of instruction may well stultify intellectual development and check that widespread formation of mental roots which is the all-important function of education. Expounding his views on education, Dr. Arnold of Rugby stated a great truth when he said, "I am increasingly convinced that it is not knowledge but the means of gaining knowledge, which I have to teach." Engineering education must aim at something more than cramming a student's mind with facts and formulas. It must strive to emancipate him from the tyranny of ready-made rules and slavish reliance on the potted and predigested form of nutrition contained in engineering pocket-books; so that he acquires the confidence to think independently and to trust his own judgment based upon a proper understanding of scientific principles. Education must aim at giving him a healthy mental digestion and that keen appetite for knowledge which a healthy mental digestion promotes, and it is hardly an overstatement to say that the soul and spirit of education is that habit of mind which remains when a student has completely forgotten everything he has ever been taught.

You will not be surprised that, holding clear convictions about the necessity of depth and breadth rather than height in engineering education, I am strongly opposed to premature specialization. Show me a youngster who has had his foundations of belief well and truly laid and I will back him at long odds to overtake and soon outrun over any line of country, one of equal natural ability whose breadth of vision and mental root formation have been cramped by premature specialization. The foundations of engineering knowledge are growing wider and yet more wide, and branches of engineering are becoming more and more closely interlocked. As an example, radio-electricity was formerly regarded as a highly specialized engineering subject, but recently its applications have penetrated to such an extent into nearly every department of engineering that it must now be treated almost as a basic subject in any curriculum which aspires to give a liberal engineering education.

Assuming that an engineering course at a University extends over a period of three years, that is none too long for establishing the basic principles common to all the main departments of engineering—Civil, Mechanical, and Electrical. In his third year the more receptive student should be given the opportunity of pursuing one or two subjects to a more advanced stage; but, just as branches of engineering are becoming more and more interlocked, so (to change the analogy) the subdivision of engineering education into a number of watertight compartments is to

be avoided. Except for the option provided in the third year of delving more deeply into one or two specialities selected from a variety of subjects, the courses provided should be the same for all.

The primary duty of a University is to give a student the opportunity of absorbing those particular forms of knowledge which, if not acquired then, probably never will be acquired, and his activities should be directed in accordance with this plan. Following this principle, it becomes almost reasonable to suggest that if a student is destined, let us say, for an electrical career, the subject he can most afford to neglect when he is at the University is Electricity, since he will get all he wants of that commodity in his subsequent experience. Unexpected knowledge is the surest means of obtaining differentiation from the common herd. A beginner in an electrical firm will get little credit for his knowledge of electricity, for in that particular direction he will be surrounded by others far more knowledgeable. But if perchance a problem involving stress calculations comes along, which he alone is capable of solving, seen against a black background of ignorance he will gain credit quite out of proportion to his merits.

Whether or no some new subject should be introduced into the educational system should, in general, be decided by the test, does it or does it not involve important fundamental ideas which, if not assimilated at that stage, never will be acquired; and, bearing in mind that the educational machine is always overloaded, the further question arises what item, if any, can be jettisoned to make room for the new activity.

If this non-specialized form of engineering education is accepted, employers, when they take on a University graduate, must not expect him to be a finished tool available for immediate use. His potentialities may be great, but at that stage he can be regarded only as a raw product, and the principle of concentration on the fundamental and less readily acquired forms of knowledge will have fashioned him, for the time being, into a lop-sided creation with many ungainly bumps and hollows. It must be left to his employers to mould him into shape, and it is to be hoped that this will be effected by filling the hollows rather than suppressing the bumps. These bumps are the indications of self-confidence and knowledge, and to operate on them will reduce the patient to a state of mental mediocrity.

In this moulding operation the students of highest quality are the most difficult to handle and the most exacting to train, since their independence of mind may cause them to ask awkward questions and to rebel against time-honoured conventional methods difficult to defend. On this account I have, to my regret, even encountered cases where employers have deliberately shown preference for young men of a lower order of intelligence, knowing that such will be more content to accept the *status quo* and more prepared to conform to the description of the practical man propounded by Disraeli, who defined the mere practical man as "the man who is content to perpetuate the mistakes of his predecessors."

Nevertheless, engineering firms are with increasing persistence asking for young men of exceptional ability, but having got them, not infrequently they have no idea how to utilize and develop this latent talent. A lengthy treatise might be devoted to this subject—indeed a text-book dealing with this topic is badly needed—but all I will say now in this connexion is that razors are poor implements for cutting bricks, and a chisel, if used as a screw-driver, is apt to lose its edge. To develop the potentialities of high-class but inexperienced engineering students, they must be set problems calculated to stretch their brains and at the earliest possible stage they should be given tasks which involve real responsibility; perhaps the most valuable part of this stage of their education being the lessons they learn from their own mistakes when such mistakes really matter. There is a saying that lilies, when they decay, smell worse than weeds, and the better the brain the lower its fall when degeneration sets in owing to repeated frustration or chronic disuse.

In many engineering organizations there exists at the top an upper stratisphere of conspicuous ability and mature judgment and at the bottom there is a ground layer of youthful enthusiasm and fresh ideas, unbalanced though these may be by lack of experience; but in between there is apt to be a stratum of high resistance and poor permeability, the abode of those who have risen as high as their limited natural ability enables them to rise, and where, bereft of ambition, they are content to remain perpetuating in a painstaking manner the mistakes of their predecessors. It is this middle layer which clogs the wheels of progress and devitalizes the enthusiasm of those young men who started their engineering careers with such high hopes and aspirations.

Whilst it is easy to point out a defect, it is more difficult to prescribe a remedy; but the solution I now propose, even as I have done in the past, is to stir up this stagnant middle stratum with more posts in the nature of personal assistants to managers or directors. Young men of proved ability, after they had completed their practical training, could thus be set to study special problems calculated to develop their originality and brain power and, vested with authority from on high, their initiative would not be thwarted as is all too likely if these efforts are not backed by influential support. The existence of such posts would also have the good effect of inducing men of exceptional ability to remain on the technical side; bringing them into close contact with managerial activities would fit them for subsequent positions of high responsibility, and might even thereby tend to discredit the prevalent and pernicious doctrine that the mentality of the technical man is too narrow for the highest positions industry has to offer.

Mathematics.

Since mathematical ability, if not acquired at an early age, will never be acquired, mathematics must occupy a prominent position in any

University course of engineering education. Mathematics has been termed the "handmaiden of Science", and with the rapid developments taking place in engineering science, the services of such a handmaid are becoming an increasing necessity. But even now, these advances are seldom the direct result of mathematical analysis, and perhaps the most valuable service this science renders to engineering is the explanation of difficulties encountered and the consolidation of a position already won, so that a further advance can with confidence be undertaken. Here I am speaking of mathematics of a really exalted character. To the real expert the type of mathematics utilized by engineers in their everyday work appears hardly worthy of the name, but only a degraded form of his art, debased by utilitarian considerations. Speaking in analogies, I would refer to the routine calculations practised by engineers as mathematics of the "tin-opening variety," and in contradistinction to real mathematicians, we engineers are more interested in the contents of the tin than in the beauty and precision of the implement employed. But some form of mathematical tin-opener is essential, since it is the only means whereby fundamental truths can be incontestably established, and empirical formulas replaced by those of a rational variety.

Mathematics is a subject which differs from almost any other form of knowledge in that to most individuals it presents a ceiling above which it is impossible to rise. When a student is endeavouring to master a particular subject, lack of natural ability can usually be overcome by extra effort; but my teaching experience leads me to believe that this does not apply to mathematics, and the fact that most students in this subject possess a definite limitation and are unable to rise above it, does not necessarily betoken a lack of effort.

Fortunately the mathematical ceiling for most engineering purposes is not very lofty and against this barrier the majority of engineering students need not bump their heads; but its existence must be recognized in any system of engineering education, and a student's analytical ability should be tested at an early stage. Even if this ceiling is below normal he may yet have the makings of a first-class engineer; but engineering principles must be expounded to him in language of a less advanced mathematical character; otherwise, at the best, he will be in the condition of "faint but pursuing", and at the worst, thoroughly dispirited, he may abandon the chase.

The most widely used tools of engineering mathematics are the differential and the integral calculus, including some of the simpler species of differential equations. Modern mathematicians are exceedingly scrupulous about the legitimacy of the operations they employ, but engineering students should not have their minds burdened with an overload of philosophical doubts. For instance, elaborate investigations relating to the convergency of series are quite unnecessary, since the direct application of simple arithmetic will soon reveal whether or no a series is numeri-

cally intelligible. Engineers in their mathematical excursions should not allow themselves to be intimidated by notice-boards which say "Fools step in where angels fear to tread." The eminent French mathematician D'Alembert gave much the same advice when he wrote "*Allez en avant; et la Foi vous viendra.*" The validity of a mathematical process may well be defended by the fact that it yields no obviously absurd results.

In teaching mathematics to students of normal ability, experience has shown me that an illogical method is often the best, and that a thorough drilling in the technique of a process can with advantage be given before the reasons underlying the process are fully understood. Thus, in teaching the art of differentiation, although the teacher, for his own satisfaction, may be permitted to give a preliminary explanation of the processes and principles involved, at that stage his explanation is not likely to make much impression with the majority of his audience. But if, after a student has practised the technique and worked out numerous examples, the reason and purpose of what he has been doing more or less automatically and blindly is once again explained, the scales will fall from his eyes and the light of true understanding will enter and remain therein.

For higher flights of modern mathematics I have a profound admiration mingled with awe and, though it may be sacrilegious to say so, this awe is now and then tinged with a slight feeling of mistrust; for as a famous mathematician has said, "Mathematics is sometimes more intelligent than the people who use it." For my own part I am only happy with the findings of mathematics when I am not more than two or three steps away from my starting-point. A greater distance is seldom necessary; elaboration of mathematics in relation to engineering problems often betokens a paucity of physical conceptions and is apt to suggest that perhaps before being placed in the mathematical machine the problem had not been reduced to its simplest possible form.

Some such simplification or idealization is always necessary before an engineering problem is susceptible to analytical treatment. This preliminary simplification calls for careful discrimination and sound judgement; otherwise factors may be left out of account which are of vital importance. As a case in point, I may mention that when the Bridge Stress Committee was investigating the oscillations set up in railway bridges by the impact of locomotives, it was only revealed at a regrettably late stage of the experimental work that the factor which really dominated the problem was the damping induced by spring movement in the locomotive, and that a mathematical analysis which left this out of account could not be trusted to give predictions of any practical value.

This, and many other cases which might be cited, point the moral that mathematical conclusions in relation to engineering problems can be accepted only after experimental verification, preferably on a full scale, since in default of this verification influences of the first order of importance may have been idealized out of existence and analysis may have been

indulging in that futile form of exercise known as "barking up the wrong tree."

Although analytical dexterity is an admirable quality in any engineering student, this form of ability should not be overmarked in assessing his merits. Mathematics is merely a means to an end, and not a culminating glory. In preliminary examinations it is well to have separate papers on this subject to probe a student's depth of knowledge in this direction and to detect the shallows; but in the final examination, mathematics should be put in its proper perspective and viewed as a means to an end, this end being the solution of engineering problems and not a display of mere analytical dexterity.

Before leaving the subject of mathematics I will just touch on that oft-debated question whether it should be taught by a man who is primarily an engineer or mainly a mathematician. It is very similar to the consideration whether French should be taught by an English-speaking Frenchman or a French-speaking Englishman. My own experience is that, in a teacher of mathematics to engineers, first-hand experience of its application to practical engineering problems is more important than superlative mathematical brilliance. You want for this purpose a man who has been all the way there and back again. The real mathematical artist has doubtless been all the way there, but his roots will have a tendency to come out of the ground, and he may find it difficult and irksome to descend to that level where, earth-born, the majority of his audience are constrained to shuffle along.

The Humanities in relation to Engineering Education.

I will now put in a plea for leavening an engineering education with some small measure of the humanities.

There is much truth in the saying that the proper study of mankind is man, and this precept should receive recognition in any liberal system of engineering education. Exclusive concentration on the materialistic and scientific aspects of his profession tends to produce in a student a certain narrowness of vision which subsequent experience may never wholly rectify. Too often one encounters the young man who assimilates with meticulous diligence every scrap of knowledge imparted to him, and in consequence passes all examinations with inevitable precision. His immediate advancement is thereby assured, and it is an absolute certainty that his diligence will carry him up to a certain level; but it is more than likely that lack of humanity and breadth of outlook will put a limit to any further advancement. At the time when his mind was most susceptible to treatment, his root development has been stunted by an over-indulgence in an ill-balanced diet and a lack of those essential vitamins which the humanistic side of education alone can provide.

It is good to have communed with the great minds of the past, but

that form of culture known as *literae humaniores* is a luxury which, in the case of an engineering student, must be left to individual enterprise, and the humanistic side of engineering education must perforce relate mainly to the present and the future. Engineering is now shaping the destiny of civilization; it has vast potentialities for both good and evil and, side by side with his scientific training, a student should have his interest stimulated towards the humanitarian, the economic, and even the ethical responsibilities of the profession he is about to enter.

To this aspect of engineering education the Council of The Institution are now giving earnest consideration. They have voiced their hope that engineering education of the future will stress more fully the economic aspects of engineering undertakings, the general principles of management, the organization of works of construction, industrial psychology, and aesthetics in engineering design; and, as tangible evidence of this educational ideal, the University of Cambridge has been given a subsidy to provide special teaching in these subjects.

In addition to its cultural value the study of aesthetics in engineering design is particularly appropriate to present circumstances, with such a vast vista of reconstruction work looming ahead. In this particular direction engineering education in the past has taken little or no interest. Students are taught to design structures which are reliable and economical, but it is very unlikely that they are given the faintest indication that in beauty of form and harmony with surroundings there are other problems to be solved of almost equal importance. When accused of indifference towards aesthetic considerations, engineers have been prone to take refuge behind the plausible but pernicious doctrine that if a structure is properly proportioned for the duties it has to perform it must be automatically pleasing to the eye. That doctrine is one of those half-truths which can be very dangerous. For mingled with truth it contains an element of complacent self-sufficiency which, if allowed to remain unchallenged, will inevitably debase the whole status of the Civil Engineering profession.

Education will have performed a valuable service if it merely indicates to the rising generation of engineers that in their designs beauty of form as well as strength must be taken into account. Reasons why some structures please and others fail to do so, when pointed out, are fairly obvious; and, once a student's eyes have been thus opened and his interest aroused, an appreciation of beauty will, in most cases, grow up by personal observation. But good taste is not determined by a mathematical equation, and artistic treatment cannot be standardized by a code of practice. The most education can do is to sow the seeds. The cultivation of these is an individual responsibility, and it cannot be expected that all the seed sown will fall on fertile soil.

Examinations.

So far I have avoided the subject of examinations, but no talk on education can ignore completely this somewhat painful topic. A sweeping condemnation of the whole examination system is an easy way of gaining the approbation of one's audience; but, whilst I share the widespread mistrust of examinations as the ultimate test of mental ability, I mistrust even more the intellectual capability of the young man who fails with monotonous regularity to surmount every examination obstacle placed in his path, and in spite of all special pleadings, I consider the inference to be drawn from oft-repeated examination failures is all too obvious. It is easy to condemn the examination system, but even its most bitter critics have no clear-cut alternative to suggest. Written testimonials are of value, but only if one is in a position to assess the veracity of the writer, since writers of testimonials have this in common with those who inscribe epitaphs on tombstones, that they are not on their oath. Unless a testimonial is almost fulsome in tone it is apt to be interpreted as damning with faint praise; consequently there is a tendency to depict all geese as swans or, at any rate, birds with very elongated necks.

There is no doubt, however, that education, particularly in Great Britain, suffers from a surfeit of examinations. Teachers have their merits assessed by the examination successes their pupils achieve; consequently they tend to keep their eyes focused on the examination syllabus, education degenerates into mere instruction, and instruction in its turn sinks to the yet lower depravity of cramming. But examinations, provided that they do not persistently obscure the view and terrorise their victims, do serve a useful purpose, and if they were eliminated, although a few ardent spirits would doubtless continue to seek knowledge for the joy of doing so, I fear that, on the part of the majority, the pursuit would be but a half-hearted and poorly attended hunt. The main purpose of examinations is to find out if a student's knowledge has become available for export. It is all too easy to satisfy oneself in this respect, but mastery over a subject has been attained only when one is able to expound its meaning and applications to someone else. Viewed from this standpoint, examinations cease to appear as vindictive impositions, to be circumvented with the minimum of effort. When one has reached that regrettable state of seniority which confers freedom from this particular infliction, the need of an examination substitute often becomes apparent and, for my own part, if I want to acquire a working knowledge of some unfamiliar subject, I put myself down to give a course of lectures thereon. On the same principle, students of ability can derive great advantage by coaching their less gifted or less advanced brethren. The consolidation and clarification of their ideas resulting therefrom will be an ample reward for the expenditure of time and effort incurred. With the same end in view, undergraduate societies at which students read papers and discuss engineering

subjects deserve every support. To encourage the timorous, variety and simplicity should be aimed at rather than depth and originality. A lively exchange of ideas on subjects within the comprehension of all, and opportunities for developing clarity in verbal explanations, should be their main purpose, and the conduct of these societies may well be guided by the dictum of a learned judge that "a restatement of the obvious is often more valuable than the elucidation of the obscure."

In connexion with such societies, senior members of the profession can help greatly by giving talks about works which they have carried out, or engineering developments to which they have devoted special attention, and providing on these occasions an opportunity for students to converse with men of mature practical experience. In education apathy can almost always be converted into explosive energy if only the right detonator is found, and such conversations may well kindle an enthusiasm which academic training has failed to arouse. With this object in view, The Institution is collecting a panel of its members who in this manner would be prepared to help the cause of engineering education. A list of possible helpers has been prepared and invitations have been sent out, but such a list must inevitably be incomplete, and I hope that any who feel a generous impulse to participate in this scheme will not hesitate to offer their services, although they may not have been formally approached to do so.

Workshop Training.

The prominence which should be given to workshop practice in the case of a University student has often been the storm-centre of heated controversy. Most certainly some such training of a preliminary character is essential, but it is not the primary duty of the Universities to turn out skilled mechanics; they have neither the facilities nor the time for doing so, and the major part of this training must be post-graduate. Before a student takes his final examination he should, however, have achieved some familiarity with and some dexterity in the use of tools, and this qualification can be attained by workshop courses in the University or, alternatively, by experience in commercial workshops during vacations; usually a combination of these two alternatives is advisable. There is also much to be said for a short workshop training sandwiched into a period between leaving school and entering the University. The manual dexterity a student acquires in such a course is of secondary importance; its primary value lies in the lessons in human psychology which this experience will consciously or subconsciously provide. The student may be too young to appreciate fully at the time the value of these lessons, but nevertheless youth to him at that stage is a great asset. He will, in consequence, find the workmen fatherly and helpful, and he will discover that they have a kindly and generous side to their nature which he may perhaps

never fully appreciate if his first contacts with British workmen are delayed to a later stage.

Apart from the foregoing considerations a short interregnum between school and a University is excellent for character formation. It develops in a young man the knack of throwing out new roots in unfamiliar surroundings. Furthermore, it gives him the feeling that he has started his professional career and, in consequence, he does not enter the University regarding it as a school with a relaxed discipline.

To get the maximum benefit from this preliminary practical experience, respite from systematic tuition in theory may for the time being be permitted. But, if this is done, the time should not exceed six months; otherwise a student's sensitivity towards book learning may receive a set-back which is more than temporary. Here, however, it is wrong to generalize, for I can recall several instances of a super-successful University career which had been prefaced by a full practical apprenticeship, during which only a meagre substratum of theoretical engineering knowledge had been acquired. But these were all exceptional cases; young men with great force of character and outstanding natural ability, who could hardly be affected adversely by any irregularity or inversion of the educational system. For normal University students the serious part of their practical training must follow their University career, and, if education has achieved its purpose, the intelligent and orderly assimilation of this post-graduate practical training will have been greatly helped and expedited thereby.

Drawing Office Training.

Drawing is another educational subject to which, in a University education, a time limit has to be imposed. The first-class draughtsman is the outcome of years of practice and experience, and a University course which specialized on this product would have time for nothing else. At a University, a grounding in drawing office methods and considerable practice in solving engineering problems by graphical processes should be given; but, though the technique of high-class draughtsmanship ought to be set before students as a goal to be subsequently attained, they cannot be expected to reach this standard of perfection in the limited time available. A taste for the actual process of drawing is a very valuable asset, and an engineer who has never developed that taste, or has allowed it to fall into disuse, places himself at a disadvantage. Handing over a rough sketch to a draughtsman may produce one solution of a problem, but there is no assurance that it is the best. Work on a drawing-board is a slow process which gives plenty of time for thought and, as the design begins to unfold, various alternatives will almost inevitably present themselves and, more often than not, the final solution has little resemblance to the original conception. Hence I would advise any young engineer to cultivate a

taste for drawing ; to regard it as a valuable accomplishment and not as a menial task associated with the less exalted stages of an engineering career.

RESEARCH AND POST-GRADUATE TRAINING.

The word Research in its application to Engineering can produce mixed emotions. It can conjure up the soul-stirring contributions to knowledge made by great scientists such as Newton, Clerk Maxwell, Rutherford, and J. J. Thomson, whilst at the other end of the scale there is the dreary vision of research being basely used as a means of obtaining a cheap degree. Without any disparagement to the great pioneers of the past, it should be recognized that outstanding distinction in research is becoming increasingly difficult to achieve. The days are past when nuggets could be found lying about ; the alluvial deposits have been worked out, and to add to our stores of knowledge deep-level mining is generally essential. Consequently, in engineering research, team-work is tending to replace individual effort, with the result that personalities have less opportunity of becoming conspicuous. This tendency must, sooner or later, be recognized in the training for research and in the granting of research degrees. Often the best approach for a beginner in research is to serve an apprenticeship in a team already at work, but under present circumstances this course may seriously jeopardize his chances of a research degree. For this particular hall-mark a premium is placed on individual effort and originality; consequently the young research worker who has his eye on a degree is generally forced to plough a lonely and often shallow furrow, instead of digging deeply into some problem of first-rate importance, guided and stimulated by a band of fellow-workers. Unless this trend is recognized, and the value of team-work is taken into account in granting degrees, the training in research for University engineering students will become increasingly limited in scope and out of touch with modern methods.

At a University, research should, as far as possible, be of a fundamental and long-range character which may have no immediate or obvious practical value. Industrial research, where quick returns of a utilitarian character are called for, must in general be left to the research laboratories of commercial undertakings, particularly since such research is often of the full-scale variety, involving specialized and costly apparatus which a University research laboratory can neither finance nor accommodate.

This question of the ever-increasing cost of engineering research is a serious consideration and suggests that in post-graduate training and research the Universities to some extent should pool their resources. At present their post-graduate activities overlap in a manner which is very uneconomical. After a student has graduated he should be free to migrate to some other University which specializes in the particular line of know-

ledge he wishes to pursue, and this change of environment will often be greatly to his advantage.

Instead of all Universities professing omniscience, one would like to see the subjects of post-graduate study apportioned to them, account being taken of their geographical position and the nature of their local industries. In this rationing process there are all the ingredients for a sanguinary dog-fight. It could be brought into effect only by invoking some high authority invested with dictatorial powers, but the gain would justify any temporary turmoil. Post-graduate teaching and research would gain strength by concentration, the channels of intercourse between industry and the Universities would flow more fully in both directions, and particular industries would know more definitely where to turn when seeking guidance, or bestowing gifts for the encouragement of that special form of post-graduate training and research in which they are interested.

Teaching.

And now I will make a few observations on the technique of teaching. The accomplishments looked for in a teacher of engineering are two- and perhaps even threefold. He is generally expected to be not only an accomplished teacher, but also distinguished in research, and to these qualifications, when a leading position is to be filled, administrative ability has to be added. These three attributes, teaching, research, and administration, are as widely separated as the corners of an equilateral triangle, and to find them all embodied in their highest development in any one single individual is almost too much to expect. Even teaching ability and distinction in research are apt to be in conflict, and if, as a teacher, a man's qualifications are " A1," it is more than likely that in research he cannot be rated higher than " B," and vice versa. In making an appointment to a post which is primarily of a teaching character, though a candidate's research record should be taken into account, this qualification, in my opinion, is often overweighted. It is not always sufficiently recognized that first-rate teaching ability is a gift vouchsafed to only a favoured few, and that its comparative rarity gives it a value which can hardly be overestimated. It is all wrong to imagine that because a man is learned he can in due course become a good teacher, and this misconception applies with even greater force to ardent disciples of research. Consumed by a divine frenzy, the research enthusiast is apt to grudge every moment spent away from his beloved occupation, and a teacher who views his task as being of secondary importance is unlikely to be a success. Students pay their fees to receive tuition, and in return are entitled to receive the best teaching which can be provided ; and, to satisfy their needs with the reluctant efforts of a man whose interest is mainly dedicated to research, is the perpetration of a flagrant breach of contract. Research is a vital

necessity in any University Engineering Department, but it must not be subsidized out of the fees paid by students.

Thus, on the staff of a University Engineering Department, two categories should be recognized, those whose primary duty is to teach and those who are mainly occupied in research; and in making and financing appointments, this division should be clearly recognized. In practice, however, this demarcation should not be too rigidly enforced. Every teacher, though his natural aptitude for research may be limited, should strive to make his modest contributions to knowledge, and every research worker will derive benefit by endeavouring to expound his ideas to an audience, though the members of this audience may sometimes have their own views about the value of this infliction.

For success in teaching long experience is essential, and the teacher who has become self-satisfied with his efforts is already on the down grade. In addition to experience certain natural qualities must have been inborn; for instance, a clear and musical voice is a valuable asset. But the most important attributes are enthusiasm and sympathy; a lecturer must face his class with the feeling that he has something perfectly splendid to tell them and they, above all others, are the young men with whom he wishes to share his soul-stirring secrets. Enthusiasm and sympathy are very infectious and, if this atmosphere is created, a lecturer's task is more than half performed. For orderly arrangement of his material and clarity of exposition he must strive continuously without hope of finality; indeed the most stimulating incentive to progress in teaching lies in the fact that finality in technique never can be attained.

If a lecturer is unfortunate enough to find his class restless or unruly, the blame almost invariably lies with him. It is generally an indication that his lecture has been insufficiently prepared and is lacking in the virtue of clarity, without which he cannot hope to hold the attention of his class. Clarity in a lecturer is a form of good manners he owes to his audience; without it all his other excellencies are of no avail, and every teacher can with advantage study that sublime message of St. Paul to the Corinthians, substituting for "charity" the equally merciful and perhaps even more kindly virtue of clarity.

There is one important word of advice I feel impelled to give teachers. When examining a pupil's work in his presence always in the first instance seek for something you can praise. If this can be done, and it is not always easy to do so, a student will pay much more heed to the condemnations you may have subsequently to make; he will take them to heart and accept them without resentment. It is a British characteristic to bestow praise much too sparingly. Most of us, young and old, benefit from an occasional dose of this tonic, and it is only the thick skinned or entirely self satisfied who don't find it invigorating and a stimulus to renewed effort.

It is a mere truism to say that the best teachers are not necessarily

those who possess the most brilliant academic records; indeed extreme mental acumen may almost be a drawback. A teacher is more likely to be in sympathy with his pupils if, in the past, he has encountered and surmounted by conscious effort just those same difficulties which confront the student of average ability; and the super-brilliant mind which has acquired knowledge almost subconsciously may have difficulty in appreciating the perplexities which beset those of lower intelligence.

Finally, on this subject of engineering teaching, I would add that, as a foundation for such a career, some practical engineering experience is essential, of an amount not less than that required by The Institution as a qualification for Associate Membership.

A question which is frequently asked is, "how do engineering students nowadays compare in ability and diligence with those of the past?" My answer is that, in general, the present generation has become more studious. Owing to the increased tempo of the educational system, there are fewer opportunities than formerly for loitering by the wayside; a student must keep moving all the time. He realizes that his mental efforts cannot be reserved exclusively for the period just preceding an examination and, though to some extent diligence may be thus forced upon him, the serious-minded and vigorous manner in which the great majority of students now pursue their studies is a cheering indication of the backbone possessed by the rising generation in this country.

Concerning ability, a general up-grade is certainly apparent, though the high-water mark of intelligence of the very best remains sensibly constant. This, I conceive, may be in accordance with a law of nature which has set a limit to human intelligence, which few attain and none surpass, and I believe that, going back as far as historical evidence can take us, the outstanding examples of human intelligence have been of equal distinction quite irrespective of age or nationality.

Advice to Young Engineers.

And now, in conclusion, I will address myself more particularly to those young men who are still only on the lower rungs of their professional ladder, but with the glorious buoyancy and optimism of youth, are confident of rising ultimately to the top. That, at any rate, is the right spirit in which to start the ascent, and the vista of sustained effort which lies ahead should only add zest to your high courage. For sustained effort is essential, and the upper rungs of the ladder are not reached by those who put their faith in any doctrine of "least effort." Academic success may and should help you to make a flying start, but the initial propulsive force of postscripts such as "B.A.", "B.Sc.", or even "Ph.D.", is soon spent, and your ultimate progress will depend on your own powers of propulsion and not on scholastic or even University distinctions. You will be judged by what you are, and not by what you have been. One of the early qualifications

you should have acquired is the power of concentration, and in developing this faculty I think modern educational methods are somewhat defective. Although I would not wholly subscribe to the doctrine propounded by that semi-serious philosopher Mr. Dooly, that "it doesn't matter what you teach a boy as long as he hates it", nevertheless it contains a substratum of truth and is a bracing antidote to the flabby idea of "education without tears", and the doctrine that knowledge must always be served up in a palatable form. Having occasionally to concentrate on a task which at first sight may not appear attractive, provides that invigorating tonic of mental discipline which in an engineering education is such an essential ingredient. In most professions, and engineering is no exception, there is much work to be done which the mentally undisciplined may regard as a bore, but boredom in the young is a shame-making exhibition, indicating lack of grit and deficiency in powers of concentration.

In planning your life think more about what you can give than what you can get out of it, and don't place having a good time in the forefront of your objectives. If you do most certainly you will be disappointed. Happiness is as intangible as the ends of a rainbow; it is a commodity which you cull from the roadside as you run your course through life; it must be regarded as a by-product, and not as the main purpose of existence. The nature and location of happiness are so elusive that one can only define it in parables. Personally I visualize it as a flower which blossoms forth as the result of successful effort; much the same idea was put forward by that great historian William Lecky, who wrote "Happiness is a jewel which requires a setting of hard work." Both these metaphors bring in the conceptions of work and effort, and of this I am quite sure, that happiness is the natural outcome of hard work, just as good health is associated with vigorous exercise.

I have spoken of various attributes which you should possess and cultivate; but the most valuable of all is that form of courage which refuses to admit defeat and, if there is one factor which more than another makes for success in life, it is the ability to draw dividends from defeat. Defeats must come to all who live adventurously, but don't for a moment confuse defeat with failure; if you do, you are doomed to fail. Don't regard defeat as an irrevocable disaster, but rather view it as a valuable experience. Seek and you will find a way of turning your passing loss into a permanent gain, and from your temporary set-back, instead of bitterness, draw forth the conqueror's spirit so finely portrayed in that stirring old English ballad which runs:

> "Fight on, my men," says Sir Andrew Barton,
> "I am hurt, but I am not slaine;
> I'll lie me down and bleed awhile,
> And then I'll rise and fight againe."

This ballad appears in a soul-stirring essay on courage by the late

J. M. Barrie, from which I might, with advantage, have given you further quotations.

But I shall finish with another extract, culled this time from a different source and perhaps not inappropriate to a conclusion, since it takes the form of a prayer. It was written by a bishop whose identity I have been unable to discover, but it is obvious that he must have been a really human divine who saw life and the essentials thereof in their proper perspective. His petition includes all the qualifications I have emphasized you should possess, with several others I might have mentioned, and its sanity and sound common sense should have made it more generally known. It reads as follows:

> "Give me a good digestion, Lord, and also something to digest;
> Give me a healthy body, Lord, with sense to keep it at its best;
> Give me a mind that is not bored, that does not whimper, whine or sigh;
> Don't let me trouble overmuch, about that fussy thing called "I";
> Give me a sense of humour, Lord, give me the grace to see a joke;
> To get some happiness from life, and pass it on to other folk."

ROAD ENGINEERING SECTION MEETING.

30 September, 1941.

FREDERICK CHARLES COOK, C.B., D.S.O., M.C., M. Inst. C.E.
Chairman of the Section, in the Chair.

The Chairman said that the last meeting of the Section had been held in April, and the Committee had thought it desirable to have another meeting before the short evenings began. It was hoped that two further meetings would be held during the coming session—probably in March and April.

Messrs. Hubert Edward Aldington and Raymond George Hubert Clements, MM. Inst. C.E., and Messrs. Arthur Floyd and Stanley James Higgs, Assoc. MM. Inst. C.E., were elected members of the Committee.

The following Paper was submitted for discussion, and, on the motion of the Chairman, the thanks of the Section were accorded to the Author.

Road Paper No. 4.

"Road Experiments on the Design of Thin Bituminous Surfacings."

By Robert Slater, M.Sc., Assoc. M. Inst. C.E.

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Introduction.

Thin bituminous surfacings or bituminous carpets ¾ inch to 1 inch thick are now widely used in place of more expensive materials defined by British Standard Specifications, as a means of restoring the riding quality of road surfaces. In order to establish the correct principles of design

for this type of surfacing, and to confirm laboratory investigations, an extensive series of bituminous carpets was laid in 1939 on the Colnbrook by-pass by the Road Research Laboratory of the Department of Scientific and Industrial Research, in co-operation with the Ministry of Transport. After exposure of the carpets to traffic and weather for 2 years, a period which included one unusually severe winter, it is possible to draw conclusions as to the limits of composition beyond which durable carpets will not be obtained. The exact limits of the most successful carpets will not be known until the experiment is concluded, but the compositions are indicated of those carpets which so far appear most satisfactory as regards durability and texture.

Thin bituminous surfacings have been used extensively in recent years as an economical method of improving the riding qualities and non-skid characteristics of otherwise sound road crusts. They are also being laid as the topping to the bituminous base course in new construction. No British Standard Specification has yet been issued for these materials, and most of the carpets have been developed under proprietary names. Such carpets embrace a wide range of compositions, but they fall roughly into the following four classes: (1) carpets containing $\frac{3}{4}$-inch aggregate and producing a coarse, very open surface; (2) carpets containing smaller aggregate with some mortar, and having medium-textured surface; (3) sand carpets in which all the material passes $\frac{3}{16}$-inch mesh; (4) surfacings formed by rolling pre-coated chippings into a sand carpet.

Although a limited number of road tests have been made on carpets of types (1), (3), and (4) the experiments described in this Paper deal chiefly with the second class; that is, carpets having a stone skeleton with the voids partially filled with mortar. In addition to the results of tests on carpets laid in 1939, some results of other tests carried out in 1937 are included.

Reports of road tests carried out by the Ministry of Transport on a variety of carpets, many of them proprietary materials, falling within the four classes mentioned above are given in the Annual Report of the Experimental Work on Highways (Technical) Committee, 1938–39. These tests have shown that at least 5 years' useful life may be expected from this form of surfacing.

Scope of the Experiments.

The carpet materials were produced by mixing together in an asphalt or tarmacadam plant four constituents, namely, coarse aggregate, fine aggregate, filler, and binder; and the experiments are concerned with the way in which the performance of the carpets on the road is affected by variations in the nature and proportions of these constituents.

A straight stretch of the Colnbrook by-pass, 1 mile long, within a mile

or two of the laboratory, was assigned to the experiment. The road is a trunk road carrying a large volume of fast traffic on a single 30-foot carriageway. More than 700 carpets were laid, each section occupying a length of 14 feet 6 inches and half the width of the carriageway. The carpets were grouped into eight series, differing as shown in Table I in their main constituents.

TABLE I.

Series No.	Stone.	Binder.
1	Granite	Bitumen 300 pen.
2	,,	Tar 1.
3	,,	Tar 2.
4	,,	Tar 3.
5	Gravel	Bitumen 300 pen.
6	,,	Tar 1.
7	,,	Tar 2.
8	,,	Tar 3.

The four main series, Nos. 1, 4, 5, and 8, were sub-divided, in the manner shown for one case in *Fig. 1*, according to the proportions of the four constituents. In the remaining four series about half the compositions were repeated with tars Nos. 2 and 3: the specifications selected were those most likely to be used in practice. Sand was used as the fine aggregate in all the carpets. For most of the carpets in each series the filler was limestone dust; but, in order to obtain comparative data about fillers, a few sections with slate dust, granite dust, and Portland cement were included.

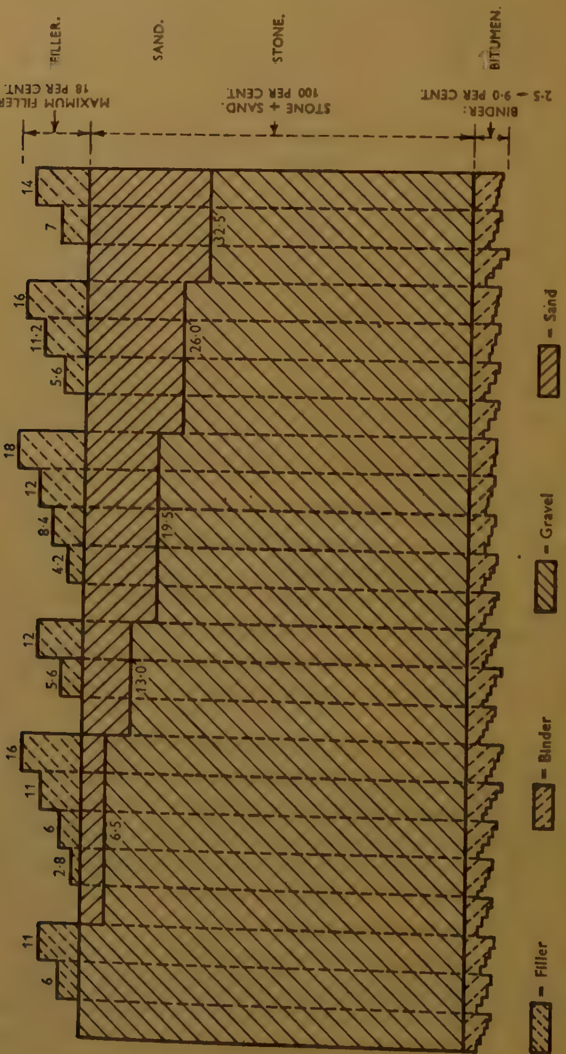
Referring to *Fig. 1*, the proportion of sand to stone was increased in six equal stages from zero up to the point at which the voids in the stone were just filled with sand-filler-binder mortar. The experiment was thus restricted to carpets having a stone skeleton, that is to carpets least likely to develop slippery surfaces. From trial lengths it appeared that the maximum sand/stone ratio permissible was 35/65 with the granite aggregate and 32·5/67·5 with the gravel aggregate.

For each of the six sand/stone ratios the filler was varied in stages from zero to the upper practical limit. The highest filler-content was 15 per cent. of the total mix. The increases were not by equal steps, but by an arrangement that facilitated comparisons with previous laboratory experiments.

The binder-content was then varied for each of these aggregate compositions, from a lower limit indicated by trial mixes as that at which the carpet was likely to fail by disintegration, to an upper limit at which early smoothing of the surface was anticipated.

The method of maintaining constant the sand/stone ratio whilst varying the filler- and binder-contents was adopted to facilitate work on the asphalt plant. In discussing the results, and in the preparation of *Fig. 2*

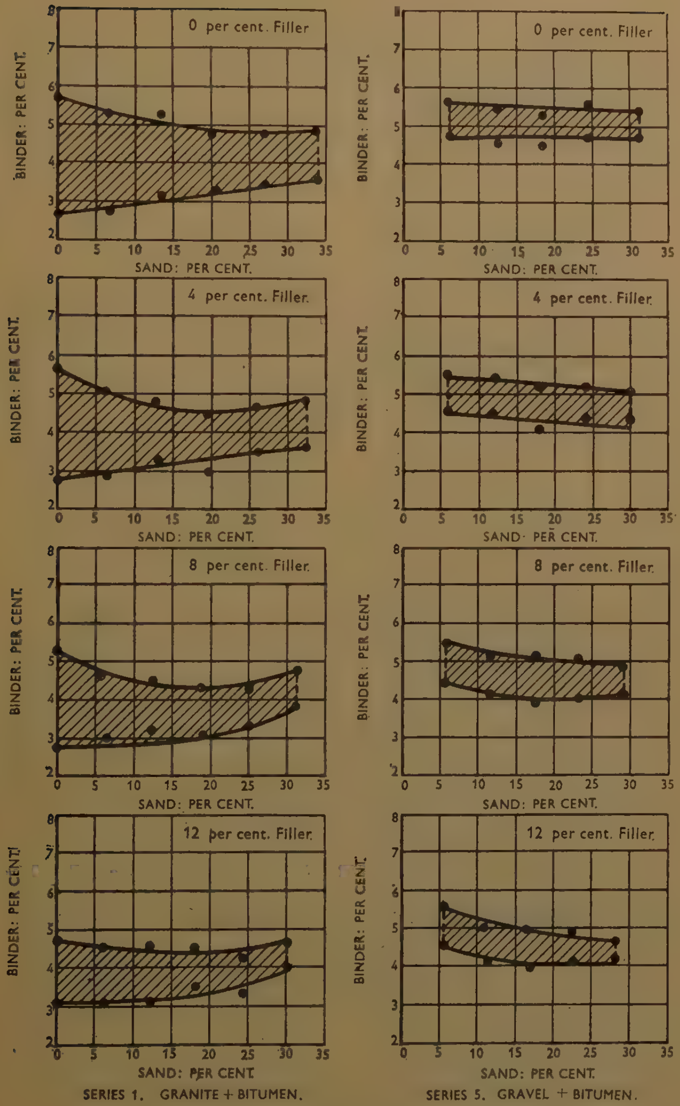
Fig. 1.



Variation of Proportions by Weight of Gravel, Sand, Filler and Binder in Series 5: Gravel + Bitumen.

and *Fig. 3*, the proportions of the ingredients have been stated on the more usual basis, as percentages of the total mix (stone+sand+filler +binder).

Fig. 2.

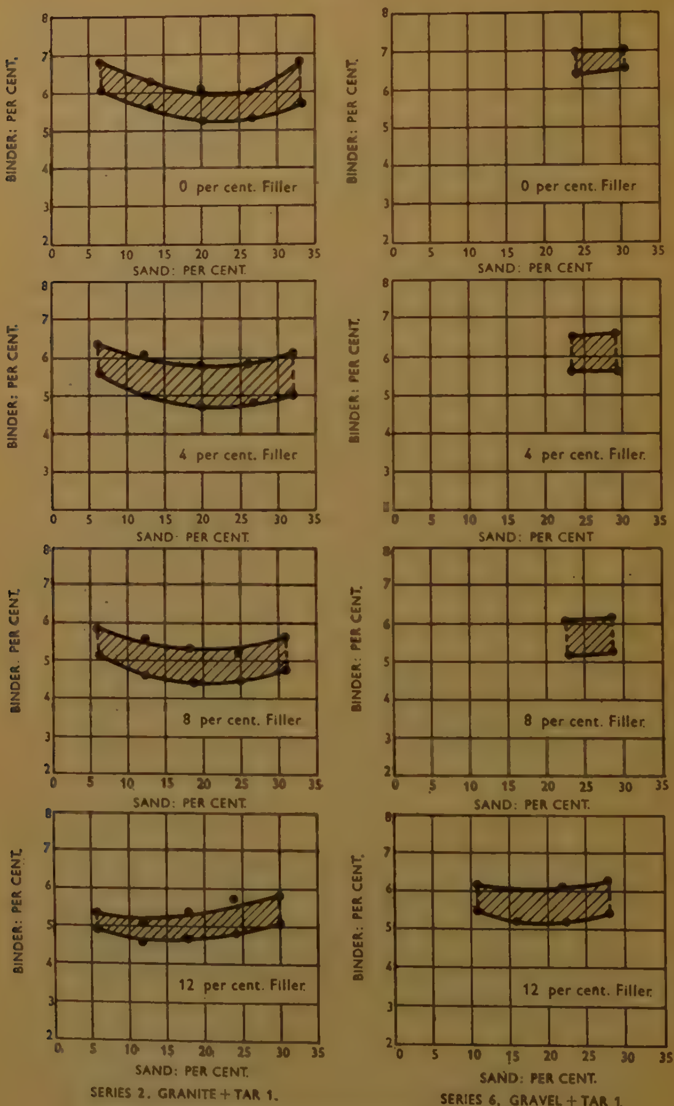


CARPETS SATISFACTORY AFTER 2 YEARS TRAFFIC FALL WITHIN THE SHADED AREAS.

EACH PERCENTAGE IS OF THE TOTAL MIX.

EFFECT OF SAND CONTENT ON BINDER LIMITS FOR GRANITE AND GRAVEL; BITUMEN CARPETS WITH VARIOUS FILLER CONTENTS.

Fig. 3.



CARPETS SATISFACTORY AFTER 2 YEARS TRAFFIC FALL WITHIN THE SHADED AREAS.

EACH PERCENTAGE IS OF THE TOTAL MIX.

EFFECT OF SAND CONTENT ON BINDER LIMITS FOR GRANITE AND GRAVEL; TAR CARPETS WITH VARIOUS FILLER CONTENTS.

Description of Materials.

Coarse and Fine Aggregate.—Of the two coarse aggregates, the granite came from Enderby quarry, Leicestershire, and the gravel, a Thames Valley gravel, from Feltham, Middlesex. Nominal ½-inch aggregate was obtained in both cases. The fine aggregate was a Thames pit sand. The gradings of these materials are given in Table II.

Table II.—Grading of Coarse Aggregates and Sand.

Particle-size.	Enderby granite.	Thames gravel.	Sand.
Passing ¾-inch, retained on ½-inch . . .	8	3	—
,, ½-inch ,, ,, ⅜-inch . . .	64	52	—
,, ⅜-inch ,, ,, ¼-inch . . .	27	39	—
,, ¼-inch ,, ,, ⅛-inch . . .	0	3	4
,, ⅛-inch ,, ,, 7 mesh . . .	0	2	6
,, 7 mesh ,, ,, 14 ,, . . .	1	1	9
,, 14 ,, ,, ,, 25 ,, . . .	—	—	9
,, 25 ,, ,, ,, 52 ,, . . .	—	—	51
,, 52 ,, ,, ,, 100 ,, . . .	—	—	15
,, 100 ,, ,, ,, 200 ,, . . .	—	—	5
,, 200 ,, ...	—	—	1
	100	100	100

Fillers.—The four fillers (limestone dust, slate dust, granite dust, and Portland cement) were chosen for their widely differing bulk densities.

Binders.—The binders were selected to enable the effect of variations in both type and viscosity to be studied. The original intention was to use five binders, namely, three tars and two bitumens, but the experiment was curtailed at the outbreak of the war; at this stage road-laying had been completed with four binders—three tars and one bitumen.

The four binders were :—

Tar No. 1.—A blended tar having a viscosity of 80 seconds at 35° C. (Equi-viscous temperature 37·7° C.).

Tar No. 2.—A blended tar as above, but containing 5 per cent. bitumen (E.V.T. 37·7° C.).

Tar No. 3.—A high-viscosity tar, having a viscosity of 70 seconds at 45° C. (E.V.T. 47° C.), prepared by cutting back a blended soft pitch with 7½ per cent. of hard pitch oil. The material had the same penetration as the residual bitumen mentioned below when both were tested at 5° C.

Bitumen.—A residual asphaltic bitumen having a penetration of 300 at 25° C.

The fifth binder would have been a cut-back bitumen having a viscosity

of 350 seconds at 25° C. It is unfortunate that the program of tests with this particular binder had to be cancelled, as it is used extensively for bituminous carpet work. The results of the road tests undertaken in 1937, which are referred to later, suggest, however, that if the work had been carried out the results would have been in good agreement with those obtained with 300-pen. bitumen.

Results of laboratory tests on the binders are given in the Appendix.

Mixing and Laying Operations.

The materials were mixed in the Laboratory's small commercial asphalt plant (capacity 2½ tons per hour), to which a few modifications had been made to meet experimental requirements. All the materials were carefully proportioned by weight immediately before mixing. About 1 ton of mixed materials was prepared to each specification. The mixture proportions were changed every 25 minutes, and from sixteen to twenty carpets were laid per day.

Analyses of samples taken as the mixed materials fell from the mixer into the lorry showed that the binder-contents were within 0·2 per cent. of the specified quantity. (For example, 6·0 ± 0·2 per cent.)

To obtain uniform conditions the carpets were laid on a 2½-inch bituminous base course, laid on the existing road surface prior to the commencement of the experiment. The mixed materials for the carpets were spread by hand-rakes and rolled with an 8-ton Diesel roller. The rate of spread was from 26 to 30 square yards per ton of mixed materials. Records were taken of the temperature of the mixed materials at delivery, spreading, and rolling of each section; the weather conditions at the time of laying were also noted.

The carpets were laid between June and September, 1939, and each section was opened to traffic on the day of laying.

Traffic and Weather Conditions.

Daily records have been kept of the volume of traffic using the road, the rainfall, and the road temperatures. The distribution of traffic across the carriageway has also been studied[1]. The traffic-density prior to the war was approximately 17,000 tons per day. During the first year of the war a 34-per cent. decrease in the number of vehicles using the road occurred, but this was accompanied by an increase in the average weight per vehicle due to the increased percentage of lorries and army vehicles,

[1] H. Booth, "Examination of Road Wear", *Chemistry and Industry*, 1939, vol. 58 (21), 501–7; 1939 (*Road Abstracts*, vol. 6, No. 507; Sept. 1939).

and the traffic was approximately 15,000 tons per day. During 1941 the figure has increased again to about 17,000 tons per day.

Since weather conditions exert an important effect upon the durability of surfacings, it should be noted that the winter of 1939–40 was exceptionally severe, causing widespread damage to roads in Great Britain. This fact, combined with the long spell of hot weather in the succeeding summer, is significant in relation to these experiments, as extremes of temperature would normally hasten the process of wear.

Results from the Experiments (After 2 Years' Wear).

The performances of the carpets in the four main series are discussed below, and the results after 2 years' wear are shown diagrammatically in *Figs. 2* and *3*. The diagrams have been drawn to show the effect of the sand-content upon the satisfactory binder limits for carpets having filler-contents ranging from 0 to 12 per cent. The percentages are expressed as percentages by weight of the total mixed materials (stone+sand+filler+binder).

The diagrams require a definition of the term "satisfactory carpet", and this is provided by saying that a satisfactory carpet is one which does not fail prematurely in any of the following five ways :—

(1) by disintegration or loss of aggregate from the surface, attributable to deficiency of binder or, in the case of certain binders, to unsuitable grading of aggregate ;
(2) by the presence of excess binder on the surface ;
(3) by bleeding of the binder during hot weather ;
(4) By the development of a smooth surface texture indicative of low sideway force coefficient (skidding resistance) in wet weather ;
(5) by deformation under traffic.

Visual inspection is sufficient to indicate whether a carpet is unsatisfactory for any of the first three reasons. Investigation of the fourth condition would normally require the use of a standard side-car equipment for measuring sideway force coefficient. As, however, the carpets are individually too short to be tested by this means at the usual test speed, of 30 miles per hour, the skidding resistance is estimated by measuring the "texture-depth" of the surface and its skidding resistance at a low speed, and by making use of a relationship between these two quantities and the sideway force coefficient at the standard speed. As regards item 5, none of the carpets has formed corrugations, but in one or two instances pushing of the material towards the curb from the inner wheel-track has occurred in carpets with high mortar-contents (that is, the closer-textured carpets).

Granite-Bitumen Carpets.—With suitable proportions of 300-pen. bitumen, satisfactory granite-bitumen carpets have been formed with

every sand-content from 0 to 30 per cent. and every filler-content from 0 to 12 per cent. (*Fig. 2*). The range of permissible binder-content varies according to the quantity of fine material (sand+filler) in the mix: in carpets with the largest percentage of voids (no sand or filler present) the range is widest, being as much as 3 per cent. (suitable bitumen-contents ranging from $2\frac{3}{4}$ to $5\frac{3}{4}$ per cent.): in the dense carpets with maximum sand and filler the permissible range is only $\frac{3}{4}$ per cent. (4·0 to 4·7 per cent.).

The lower limit of binder-content shown in *Fig. 2* is surprisingly low, and in most instances represents the lowest binder-content actually laid; and it may be concluded that the use of too much bitumen rather than too little is the chief point to guard against when this type of surfacing is laid on a heavily-trafficked road. It will be seen that except in the most open-textured carpets the upper limit is less than 5 per cent. of binder.

The carpets containing 0 to 15 per cent. of fine material are in very good condition and have an open-textured surface. Even a carpet consisting of $\frac{1}{2}$-inch granite with no sand or filler and only $2\frac{3}{4}$ per cent. of bitumen—in effect nothing more than a $\frac{3}{4}$-inch layer of pre-coated chippings—is still in good condition. The carpets with 15 to 30 per cent. of fine material are of medium texture and are quite satisfactory provided the bitumen-content is not too high. With 30 to 35 per cent. of fine material the carpets have a close-textured surface, and with more fines than this they are tending to become smooth.

After 2 years' wear carpets having compositions within the following limits are the most satisfactory:—

Constituent.	Percentage by weight of total mixed materials.
$\frac{1}{2}$-inch granite	75–85
Sand	5–15
Filler	0–6
Bitumen	4–4·5
(Gallons of bitumen per ton of aggregate	$9\frac{1}{4}$–$10\frac{1}{2}$)

Granite-Tar Carpets.—Granite-tar carpets have been laid using tar No. 1 (a blended tar having a viscosity of 80 seconds at 35° C.) and the same aggregate gradings as in the bitumen trials. Satisfactory results have been obtained with all but the most open-textured surfacings.

The results shown in *Fig. 3* indicate that the durability of tar carpets depends to a large extent upon the quantity of fine material in the mix; too high a percentage of voids in the carpet is undesirable. Thus carpets laid with no sand or filler and up to $6\frac{1}{2}$ per cent. of tar (13 gallons per ton of aggregate) disintegrated during the first winter, and those with less than 10 per cent., with two exceptions, deteriorated during the second winter. In both the tar and the bitumen series, where high binder-contents have been used with small quantities of fine material, the carpets are open-textured in the lightly-trafficked portion from 11 to 15 feet from the curb, but have compacted under the wheel-tracks in the inner traffic

lane and present a very patchy appearance. With 10 to 30 per cent. of fine material good medium-textured carpets have been formed, provided the tar-content is within the limits shown in *Fig. 3*. The range of permissible binder-content with these carpets amounts to about 1 per cent. in most cases. Where 30 to 40 per cent. of fine material has been used the carpets are strong but close-textured, with the upper edges of the granite only just proud of the sand mortar.

There is very close agreement between the performance of the carpets containing tar No. 1 and tar No. 2—a blended tar of similar viscosity, but containing 5 per cent. of asphaltic bitumen. So far the incorporation of bitumen in the tar has had no noticeable effect upon the performance of the binder.

Tar No. 3, a high-viscosity tar (70 seconds at 45° C.) has been satisfactory only with aggregate of the same gradings as tars Nos. 1 and 2, but apparently a wider range of permissible binder-content, represented by an extension of the upper limit amounting in some cases to 1 per cent. of binder, can be used successfully. These conclusions are tentative and may require some amendment when information is available from results obtained after a longer period.

The following range of compositions has given the most satisfactory results after 2 years' wear :—

Constituent.		Percentage by weight of total mixed materials.
½-inch granite		65–75
Sand		15–25
Filler		4–6
Tar No. 1 or No. 2.	80 seconds at 35° C.	5·2–5·8
	(Gallons per ton of aggregate	10¼–11½)
or Tar No. 3.	70 seconds at 45° C.	5·7–6·3
	(Gallons per ton of aggregate	11¼–12½)

Gravel-Bitumen Carpets.—A number of good compositions have been obtained with gravel aggregate and 300-pen. bitumen, but, considered as a whole, the carpets compare unfavourably with the granite-bitumen compositions. The addition of fine material is necessary to obtain durable carpets, and for the same grading of aggregate the permissible range of binder-content is less with gravel than with granite.

The gravel-bitumen carpets with less than 5 per cent. of fine material disintegrated during the first winter, and most of those with 5 to 15 per cent. have lost stone from the surface during the second winter. The carpets with 15 to 25 per cent. of fine material are in good condition, strong and of medium texture. With 25 to 35 per cent. the carpets are satisfactory but close-textured, and with more than this they are tending to become smooth.

The following range of compositions has given the most satisfactory results after 2 years' wear :—

Constituent.	Percentage by weight of total mixed materials.
Coarse aggregate	70–80
Sand	10–20
Filler	4–8
Bitumen	4·5–5·0
(Gallons per ton of aggregate	10½–11¾)

Gravel-Tar Carpets.—Of gravel carpets laid with tar No. 1 as binder and various sand- and filler-contents, only those that have compositions falling within the narrow limits shown on the right-hand side of *Fig. 3* are still satisfactory.

The open-textured carpets with less than 10 per cent. sand disintegrated during the first winter, and the medium-textured carpets with 10 to 20 per cent. of sand and various filler-contents deteriorated during the second winter. The most satisfactory carpets are those with 25 per cent. of sand and 4 to 8 per cent. of filler; they are inclined to be close-textured, but there is little doubt that they will last for some years. With more than 35 per cent. of fine material, the carpets appear strong but smooth.

The lower limit of permissible binder-content has been determned for all those gradings of aggregate that have so far proved satisfactory, but in some instances the higher limit has not been determined. This is because in planning the series the permissible range of binder-contents was assumed to be the same as for the granite-tar carpets. Gravel has been found to require more binder than the granite, however, and even carpets with the highest binder-contents have given satisfactory wear. The upper limit of permissible binder-content is therefore beyond the range of the present tests.

The carpets laid with tars Nos. 2 and 3 have given performances similar to those described above for carpets containing tar No. 1. The maximum binder-content for tar No. 3 has not been determined, but it appears to be higher than for tar No. 1.

The main conclusions are that open-textured gravel carpets with these types of binder should be avoided, and that even with medium-textured carpets the permissible limits of the proportions of the constituents must be carefully observed. The following range of compositions has been found to provide the best results so far :—

Constituent.	Percentage by weight of total mixed materials.
½-inch gravel	62–67
Sand	23–27
Filler	4–8
Tar No. 1 or No. 2	5·5–6·0
(Gallons per ton of aggregate	11–12)
or Tar No. 3.	6·0–6·5
(Gallons per ton of aggregate	12–13)

Discussion of Results.

Figs. 2 and *3* illustrate in a summarized form the performance of a large number of carpets. The outline of the curves limiting the composition of satisfactory carpets will doubtless change as the results of further observations become available, and a full explanation of the shape of the curves cannot at this stage be put forward. It is noteworthy that there is no support for the theory that the binder-content should depend upon the surface-area of the aggregate and that it should be increased as the fines-content (sand and filler) of the mix increases. The tendency is rather in the other direction : the more the voids in the coarse aggregate are filled with sand and filler, the thinner is the film of binder needed to hold the structure together.

In addition to their practical significance, the results will be useful as a check upon the validity of laboratory tests and will assist in studying the usefulness of road-testing machines.

Effect of the Volume of Traffic upon the Range of Binder-Content.—The results illustrated in *Figs. 2* and *3* are based upon the condition of those portions of the carpets lying from 3 to 11 feet from the curb. The appearance of this width, particularly in the mixes containing small percentages of fine material, is in many cases very different from that of the portion 11–15 feet from the curb ; the inner lane may have become close-textured, with excess binder on the surface, while the strip in the centre of the road is still open-textured. The study of the transverse distribution of traffic already referred to shows that the intensity per foot-width in the wheel-tracks of the inner traffic lane is about twice the mean intensity and three times the intensity in the centre of the road. In preparing a specification for a bituminous carpet, therefore, consideration should be given to the volume of traffic likely to use the road. The limits of binder-content given here are for a heavily-trafficked main road ; for a road carrying appreciably less traffic or, for instance, an aerodrome runway, an increase in the upper limit is possible without risk of forming a smooth surface. For example, in the granite-bitumen carpets recommended on p. 27, *ante*, the binder-content could be increased from $4\frac{1}{2}$ per cent. to $5\frac{1}{2}$ per cent. under these conditions. Since, in the lightly-trafficked road, the carpet is less compacted and the binder in the body of the carpet is thus more exposed to weather, it is desirable that a thicker film should be used.

Effect of the Nature of the Aggregate.—Although only two coarse aggregates have been used in the experiments, the results show very clearly the important effect of the nature of the aggregate upon the performance of a bituminous carpet. Good carpets which are expected to last for many years have been formed with both the granite and the gravel aggregates, but greater latitude in the proportions of sand, filler, and binder has been found possible when the aggregate is granite. Granite carpets with fairly high void-contents appear to be capable of resisting disintegration for

years, while gravel carpets of similar grading have already failed; in fact, it seems necessary for a gravel carpet to have the minimum of voids if long life is to be obtained. The difference in the behaviour of carpets made with granite and with gravel aggregates is associated with the differences in shape, surface-texture, and mechanical strength.

The results of earlier tests, carried out in 1937, are in agreement with these conclusions. On that occasion bituminous surfacings ¾ inch thick were laid, consisting of ½-inch supplies of commercial granite, quartzite, slag, and gravel, mixed with 5 per cent. of filler and 3·9 per cent. of cut-back bitumen (viscosity 340 seconds at 25° C.). The granite, quartzite, and slag carpets are still in very good condition, but the gravel carpet began to disintegrate after two winters.

This experiment showed also that the crushing strength of an aggregate need not be particularly high. The crushing strength of the slag in this case was less than half that of the granite.

A further extension to the study of aggregates suitable for use in bituminous carpets was made in 1940, when some of the original carpets were replaced. Tar carpets were laid with eight typical aggregates, selected from different parts of the country—two granites, two limestones, two slags, a whinstone, and a gravel. The gravel carpet was laid to the composition recommended above, and the other seven to the composition for granite given on p. 29, *ante*. All the carpets are satisfactory after a year, but those made with slag appear as though they would have benefited by having a higher binder-content.

Effect of the Nature of the Binder.—Good carpets have been obtained with all four binders in association with both aggregates. The range of design is much greater with both aggregates when bitumen is the binder; greater latitude is possible in the grading of aggregate, and a wider range of binder-content is permissible on the open- and medium-textured carpets. This is thought to be connected with differences between the weathering properties and temperature susceptibilities of the two binders.

As has already been mentioned, the addition of 5 per cent. of asphaltic bitumen to the blended tar has, so far, had no effect upon its performance.

Effect of the Quantity of Filler.—The filler used for most of the experiments was limestone dust, and the results given below relate to this material.

The quantity of filler in the mix affects the mixing and laying operations, the surface-texture, and the durability of the carpet. The mixtures without filler were more easily and quickly mixed, but the sand tended to segregate from the coarse aggregate to a greater extent than when a moderate quantity (say 4–8 per cent.) of filler was used. With more than 10 per cent. filler the mixing-time was prolonged, and when a high sand content (for example more than 25 per cent.) was also used the mixture was generally stiff and difficult to lay.

Since the surface-texture of the carpet becomes less open as the filler

content is increased, a higher filler-content is not desirable, because even with a moderate sand-content there is a possibility of the carpet being slippery. To safeguard against the production of a slippery surface it is also necessary to reduce the upper limit of the binder-content as the filler-content is increased; the addition of filler therefore reduces the permissible range of binder-content.

So far no evidence has been obtained that the filler-content affects the durability of granite-bitumen carpets; equally good results have been obtained after 2 years with 0·4 per cent. and 8 per cent. of filler, and it may be some time before any benefit is apparent. The open-textured granite-tar carpets, however, have been improved by the addition of from 4 to 8 per cent. of filler. Increased durability is also obtained by the introduction of filler in the gravel carpets of medium sand-content, with both tar and bitumen as binder; for example, gravel-tar carpets containing 25 per cent. of sand and from 4 to 8 per cent. of filler are satisfactory, while the carpets with similar sand- and binder-contents but no filler are disintegrating.

The presence of filler is not essential, however, as a composition that has failed through a deficiency of filler can usually be improved by increasing the binder-content. This result suggests that one action of the filler is to protect the binder from weather action.

Effect of the Nature of the Filler.—Laboratory tests have shown that the effect produced upon a binder by adding filler depends not only upon the quantity added but also upon the physical properties of the filler. The inclusion of comparative tests on fillers in these experiments is intended to check certain conclusions drawn from the laboratory work. Whilst it is not possible at present to state from the road experiments a law governing the substitution of one filler by another, it is clear that substitution on a weight-for-weight or solid-volume-for-solid-volume basis is liable to alter the performance of the carpet very materially.

Conclusions.

The present conclusions may be summarized as follows:—

1. By choosing suitable proportions of fine aggregate and binder good results on heavily-trafficked roads can be obtained from $\frac{3}{4}$-inch carpets made with either granite or gravel aggregate and bitumen or tar binder.

2. The combination of coarse aggregate, sand, filler, and binder giving the most satisfactory results in each series is:—

$\frac{1}{2}$-*inch granite and bitumen:* 5–15 per cent. of sand, 0–6 per cent. of filler, and 4–5$\frac{1}{2}$ per cent. of 300-pen. bitumen (9$\frac{1}{4}$–10$\frac{1}{2}$ gallons per ton of aggregate).

$\frac{1}{2}$-*inch granite and tar:* 15–25 per cent. of sand, 4–6 per cent. of filler, and 5·2–5·8 per cent. of tar No. 1 or No. 2 (10$\frac{1}{4}$–11$\frac{1}{2}$ gallons

per ton), or 5·7–6·3 per cent. of tar No. 3 (11¼–12½ gallons per ton).

½-*inch gravel and bitumen:* 10–20 per cent. of sand, 4–8 per cent. of filler, and 4½–5 per cent. of 300-pen. bitumen (10½–11¼ gallons per ton).

½-*inch gravel and tar:* 23–27 per cent. of sand, 4–8 per cent. of filler, and 5½–6 per cent. of tar No. 1 or No. 2 (11–12 gallons per ton), or 6–6½ per cent. of tar No. 3 (12–13 gallons per ton).

3. Granite aggregate is preferable to gravel, since greater latitude is possible in selecting the grading of aggregate necessary to produce a durable carpet.

4. Both granite and gravel aggregate can be used over a wider range of grading with bitumen than with tar.

5. The carpets containing the three tar binders show no outstanding difference in road performance. No noticeable alteration in behaviour has been produced by the addition of 5 per cent. of bitumen to a blended tar.

6. For the same grading of aggregate, gravel carpets require more binder than granite carpets, the increase being about 0·5 per cent. in the medium-textured carpets.

7. The incorporation of filler in the mix is not essential, although for a given binder-content it has improved the durability of certain carpets—particularly those with gravel aggregate.

8. For the same aggregate composition more binder is desirable in open-textured carpets on lightly-trafficked roads than for those on heavily-trafficked roads.

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The supervision of the constructional work on the Colnbrook by-pass was undertaken by the Ministry of Transport.

The Paper is accompanied by three sheets of diagrams, from which the Figures in the text have been prepared, and by the following Appendix.

APPENDIX.

Properties of Tars.

	Tar No. 1.	Tar No. 2.	Tar No. 3.
Origin of tar	Blend, 50/50 high and low aromatic.	As No. 1, plus 5 per cent. bitumen.	As No. 1
Process of preparation	Distillation to base 27° R. and B.	As No. 1.	Distillation to soft pitch, 22·6 seconds at 60° C.
Cutting-back oil:			
Per centage used	7	7	7½
Specific gravity	1·042	1·058	1·103
Distillation	5 per cent. at 215° C. 10 per cent. at 223° C. 50 per cent. at 277° C. 70 per cent. at 323° C.	5 per cent. at 224° C. 10 per cent. at 235° C. 50 per cent. at 310° C. 70 per cent. at 343° C.	5 per cent. at 289° C. 10 per cent. at 317° C. 50 per cent. at 370° C. 70 per cent. at 390° C.
Viscosity of final product:			
British Road Tar Association—Viscometer	81 seconds at 35° C.	76 seconds at 35° C.	70·2 seconds at 45° C.
Equi-viscous temperature	37·8° C.	37·4° C.	46·8° C.
Specific gravity at 100° F.	1·203	1·200	1·206
Test—standard method:			
Water	Trace.	Trace.	Trace.
Distillation:			
St—200° C. (*a*)	Trace.	Trace.	0·1 per cent.
200–270° C. (*b*)	6·23 per cent.	4·6 per cent.	3·0 ,,
270–300° C. (*c*)	6·08 ,,	7·5 ,,	4·4 ,,
Phenols	0·86 ,,	0·5 ,,	0·4 ,,
Naphthalene	1·5 ,,	0·8 ,,	0·4 ,,
Free carbon	16·0 ,,	13·4 ,,	18·7 ,,
Ring and ball on pitch	44·4° C.	43·2° C.	42·0° C.
Ratio *b/c*	1·03	0·61	0·68

Properties of Asphaltic Bitumen.

Specific gravity at 15° C.	1·03
Softening-point (ring and ball)	35° C.
Penetration at 77° F. (25° C.)	295
Ductility at 77° F. (25° C.)	+100
Solubility in carbon disulphide	99·8

Discussion.

The Author, in introducing his Paper, showed a series of lantern-slides. He observed that many thousands of miles of thin bituminous surfacings had been put down on the roads of Great Britain during the past few years, but very little information had been published as to the results that had been obtained. No British Standard Specification had been issued and the Road Research Laboratory had thought that a proper understanding of the subject could best be provided by a systematic series of tests on carpets in which the voids in the coarse aggregate varied from a maximum (with no fine material) to a minimum where they were completely filled with mortar. Seven hundred tests, in which the nature and the proportions of the constituents were varied, had been carried out on a mile of road.

The results given in the Paper were those which had been obtained after 2 years. It was considered that a 2-year test was sufficient to show whether a carpet was reasonably good; but 6 or 8 years were required to define the best compositions.

The conclusions arrived at after 2 years were that it was possible to make a good carpet with gravel or granite with either a tar or a bitumen binder; that granite was preferable to gravel, because a wider latitude of grading was possible; that with neither aggregate was a filler essential, although it was desirable in a gravel carpet and also beneficial in a granite-tar carpet; and that probably different recommendations would be made if a similar experiment were carried out on a more lightly-trafficked road. Finally, it was interesting to note that in the experiment no carpets had failed by corrugation, and it seemed that when a carpet failed in practice by corrugation that was probably a throw-back to the state of the old road underneath, which had not been either planed or levelled before the carpet was laid.

Dr. W. H. Glanville observed that the experiment with which the Paper dealt was the most extensive that had been carried out anywhere in the world on bituminous road surfacings. It had been possible to control the manufacture of the carpets and record the conditions under which they were tested to a high degree of accuracy.

The experiment was planned by the Road Research Laboratory in 1938. It was felt to be essential to establish a link between what happened on the road under ordinary road conditions and the results of laboratory tests. The experiment had shown that many of the deductions drawn from laboratory tests needed modification in important particulars. It was extremely difficult to carry out laboratory research on a road surfacing of the kind in question, because so many years, in fact, the lifetime of a carpet, were required to check thoroughly and absolutely any laboratory

finding. It was partly for that reason that in the series of tests described by the Author the method had been to cover a range far in excess of anything that would be found in normal practice, so as to ensure that the successful carpet would be defined by carpets which failed at each end of the range. Thus it had been possible to narrow the range of satisfactory carpets gradually, pointing the way to a satisfactory specification; and although the tests had been in progress for only about 2 years, it was possible to prepare specifications.

In war time it was more than ever important that local materials should be used to the best advantage and to the greatest possible extent, so as to avoid transport costs and importing materials. The tests described had indicated the limits within which the gradings must fall if good gravel carpets were to be obtained, and also the percentage of binder that should be used when tars were employed; and those were valuable and useful results.

The Author had not referred to all the incidental experimental work which had been done in connexion with the experiment. The traffic passing along the road had been recorded automatically, the temperatures on and beneath the surface had been recorded, and automatic records had also been made of the periods during which the surface of the road was wet. The traffic-distribution had been measured and very careful records had been made of the surface texture and of the surface changes which had taken place from time to time. The investigation had, in fact, been very comprehensive.

Many other tests had been planned before the war. It had been the intention to use other binders, such as cut-back bitumen, which were in common use, and to repeat the experiment on a lighter-trafficked country road. Unfortunately the war had curtailed those activities, and, although the examination of such problems was being continued to some extent, most of them would have to remain in abeyance until after the war. Nevertheless he felt that knowledge on the subject of road surfacings had been increased considerably. Some points which many road engineers had felt in the past to be right had been confirmed, and many new lines had been indicated. The Author, who had played a very important part in all the experimental work, had also been responsible for the preparation of the carpets and for the observations made upon them.

Dr. P. E. Spielmann considered that gratitude was due to those investigators who were content to undertake what was presumably for them dull and slogging work, without sensational results, although it was of the highest value to the industry covered by the research.

Two minor points had attracted his attention. Firstly, the information given in the Paper justified the complaint which had been made for some time by those engaged in the tar industry, who said: "Why spoil good tar by adding bitumen to it?" Apparently the bitumen had not done very much good in the mixtures used in the experiments. Secondly, the state-

ment that the traffic amounted to 17,000 tons per day really did not mean very much. No information was given as to whether, for example, there was a very large number of taxicabs or a relatively small number of 10-ton lorries, and that might make a great difference to the history of the road. He had attempted to elucidate that matter some time ago, but the two crucial factors in his formula, on which he had consulted experts, had not withstood the criticisms made in the discussion of his Paper. He hoped, therefore, that investigation might be instituted so that the traffic passing over the road per day could be defined rather more accurately than merely by the quantity in tons.

Mr. H. S. Keep stated that at least 9 years had elapsed since thin surfacing had first been laid in Great Britain, and large-scale experiments were started in 1934. Certain principles had become apparent quite early, and it was clear that certain factors were of importance in the design of thin carpets. He had studied the Paper, but had not been able to discover that anything of a novel character had been brought out by the research described. A number of the points had been known or believed to be true before, such as the poor affinity of tar and bitumen for gravel and the necessity for increasing the quantity of sand when gravel was used as an aggregate. Experience had shown that bitumen was a more satisfactory binder than tar in carpets, and it had also been known that open-textured carpets afforded a greater latitude in the quantity of binder than the fine-graded carpets. The value of the Paper and of the research to which it referred lay rather in the assignment of quantitative values to the influence of the factors to which he had just referred.

The Author had made a clear differentiation between the results obtained with granite and those obtained with gravel. He had stated that the gravel used was Thames gravel, but Mr. Keep suggested that greater prominence should be given to its origin because it had been a fairly general experience that Thames gravel was a very difficult material to deal with, whilst some other gravels, such as that obtained from Staffordshire, were much more amenable.

Had the Author's researches indicated the particular function of the additional sand which had to be added to gravel carpets? Did it simply improve the adhesion, or did the reduction in the size of the voids go so far as to introduce capillary forces and so increase stability, or was it just a case of the interlocking of the granular particles? Any of those three, or some combination of them, might be the function of the additional sand.

The Author had described the effect of traffic upon the thin carpets. There was, however, one danger to be noted. The Colnbrook by-pass carried a considerable volume of traffic—17,000 tons per day. That was sufficient to provide a very good test for the good carpets, but it did not afford the same test for the more open-textured carpets, and particularly those carpets with little sand and a small quantity of binder. Even the most lightly-trafficked longitudinal strip of the Colnbrook by-pass carried

considerably more traffic than many of the roads on which thin carpets were laid, and it might well be that a carpet which would be sufficiently stable under the traffic on the Colnbrook by-pass would fail by disintegration on a country road.

Mr. Arthur Floyd observed that, as a county engineer, he had to use very largely the material which was commercially available to him, and the information given in the Paper would therefore be invaluable. So far he had had to rely on what the trade could provide in the way of thin carpets; but he did not complain, because the commercial products had been remarkably successful.

No reference had been made to slag, of which a considerable quantity was used by road engineers. It was a very "chancy" material, with all sorts of varying qualities; but it was used extensively, and any information about slag in relation to granite would be invaluable.

It was well to bear in mind the history of the use of thin carpets. It was common experience, he believed, that the ordinary methods of tar spraying, if they were 100 per cent. successful, produced a 100-per cent. result. In bad weather or with bad workmanship corrugation or scabbing occurred, that was, the chips were broken away; and in a rather frantic effort to avoid that drawback the improved surface had been invented.

In his county certain lengths of open carpet had been down for about 8 years, and most of them had had to be treated very carefully during the last 3 years, as after 5 years they had begun to show signs of disintegration. Bearing in mind the Author's point about the content of the filler and the sand, he was not certain that one should not abandon the idea that had been prevalent when the thin carpet was first used, namely, that it had of necessity to be a rough carpet simulating surface dressing. It was possible that more wear might be obtained from a carpet which contained much more filler and was quasi-asphaltic in character. In his area considerable lengths of such material had been applied as a carpet in exactly the same way as the open carpet was employed; that carpet had been down in one case for 11 years, during which period it had not been mended at all, and it looked as if it would be there for another 3 or 4 years. He thought that at the moment thin carpets were regarded as merely an improvement on surface dressing, and that road engineers ought to consider how far they could introduce filler into the material, which, owing to its careful composition, would still be non-skid but, not being of too open a texture, would give considerably increased durability and wear.

Mr. A. G. Tarrant said that certain points in connexion with the Paper were of particular interest to him because he had been associated with the planning of the experiment.

Mr. Floyd had referred to the use of slag. Given several sorts of aggregate, several sorts of binder, filler, and tar, those engaged in carrying out the experiment had tried to find with how few carpets the ground could be properly covered, and the number became astronomical. They therefore

took the two most different aggregates, granite and gravel, and were able to reduce the number to about 700. They took another bold step and used only a 15-foot section length, although they felt that that would be justifiable only if the control on the work were good enough to enable every square yard of the section to be like every other square yard. He thought that their view had been confirmed by the coherence of the results. He suggested that in other experimental work that principle might be used further, because it enabled a sufficient number of sections to be put down on the same length of road, with the same traffic, starting at the same time, and at a reasonable cost, which could not possibly be done if longer sections were used. He wished to emphasize that really good control was necessary.

The materials used in the experiment were mixed in an ordinary commercial $2\frac{1}{2}$-ton-per-hour plant—the kind of plant built for export purposes—with only very small additions to secure better control. The control did not retard the work appreciably, sixteen to twenty carpets being laid regularly, day after day, throughout the whole experiment, and the mixture proportions being changed every 25 minutes. That showed that control could be effected; and if the cheap materials available, such as gravel, were to be used, such control must be maintained.

Dr. T. Lonsdale considered that the method of using short sections, with a slight change in one of the variables from section to section, was a very useful research method. So far as he was aware, that was the first time it had been used. He hoped that the Author would be able to continue the work, so as to study a large number of other variables. Thus information would be accumulated and would probably confirm many of the vague opinions now held and provide a foundation of definite knowledge.

Mr. H. E. Aldington considered that the whole problem of thin carpets deserved close study by everyone interested in the maintenance of roads. Unless such carpets were very well laid (and they could not be so laid unless they were based upon informed opinion on the subject), those who laid them were doing so without justification, because unless 5 or 6 years' wear could be obtained from a carpet there was no justification for laying it.

It had been stated that carpets had been developed owing to the difficulties that arose in connexion with tar spraying. He knew of many roads where tar spraying had been carried out carefully with very good chippings, which did, in fact, give a very useful and satisfactory surface; but the advantage of a thin carpet in comparison with tar spraying was that the former was a sound and more scientific solution of a road maintenance problem. Road engineers were gradually getting away from the old rule-of-thumb methods and were evolving carpets and surfacings based upon scientific investigation; and in that connexion the Paper was very valuable.

The Author had mentioned five ways in which carpets could fail, the first being "by disintegration or loss of aggregate from the surface, attributable to deficiency of binder or, in the case of certain binders, to unsuitable

grading of aggregate." Mr. Aldington had seen a tar carpet fail on a road situated at a fairly high altitude, following very severe winter weather. His conclusion was that that particular carpet was not sufficiently dense, with the result that water penetrated it; and during the very severe weather, several stretches of the tar carpet failed. He thought that that was corroborated by the information given in the Paper.

The second cause of failure given was "the presence of excess binder on the surface." He understood that to mean an excess of binder on the road on which the tar carpet was to be laid, and if that was the case he agreed with the Author, because he had seen many examples of carpets failing when laid on roads which had been tar-sprayed for a number of years; the surface was too fatty for the carpet to be put on and in hot weather and under traffic the composition of the carpet was entirely altered by the excess tar on the surface working through.

In the Author's conclusions it was very striking that the combination of granite and bitumen had given such excellent results. Equally good results could be obtained with slag and bitumen. Whilst it was important, with the present difficulties in transport and in the supply of materials, to make use of local materials, supplies of granite and slag could be obtained in peace time; and owing to the fact that the carpets had to be manufactured in bulk at a central plant, the best materials should be used, with up-to-date plant to control the production of that scientific surfacing material, and everything depended upon that. From a manufacturing point of view it was desirable to make the specification for the mix as simple as possible, consistent with a good product, so that the possibilities of error could be reduced.

Mr. A. W. Jarman hoped that Mr. Aldington's remarks would not be regarded as emphasizing a possible aspect of the Paper which had not previously occurred to him, namely, that it might encourage the people who made carpets to take liberties with their composition. Those who had had to do with the supply of thin carpets had been rather conscious from time to time that variables other than the binder had entered into them, although the binder was always blamed for any defect; and he thought that care should be taken, in assessing the merits of the ingredients of the various compositions, to assess them not on the basis of allowing the maximum tolerance but rather, as far as possible, on their absolute behaviour.

With regard to the type of carpet which was now recommended, he knew that the recommendation had been made on a fairly generous basis; in other words, the experiments had been designed to determine the correct principle of design of a carpet, and the tolerances stipulated were those which might be expected to give the most satisfactory results; but he wondered whether they were really representative of the hundreds of miles of surfacing which had, in fact, already been laid. He felt a little doubtful whether types of carpet containing so much fine material as

was recommended in the Paper represented, in fact, the major portion of the proprietary carpets; and he thought it would be agreed that proprietary carpets had hitherto provided the largest number of such surfacings.

Another aspect of the Paper should also be taken into consideration. Dr. Glanville had emphasized the advantage of using local materials; but the particular significance of that during war time was not so great as might at first be expected, because the quantity of surfacing now proceeding was very small in relation to the normal peace-time developments. In peace-time many worthy citizens earned their living by selling materials to produce carpets at some considerable distance from the mixing-plants where they were prepared, and road engineers bought carpets at considerable distances from the areas under their jurisdiction. It would appear, therefore, that there was some justification for the materials being transported an appreciable distance; and that introduced a new factor, namely, the ability of the materials to be transported some considerable distance, and often to be laid a week, or even a month, after they had left the mixing-plant. He understood from the Paper that the majority of the sections treated so far had been laid within almost a matter of minutes of mixing, and that was a state of affairs that was not very readily applicable to practice. In particular, he wondered whether the quantity of fine material used would be suitable for a carpet that had to be laid some time after it had been mixed; and, of course, it was quite obvious that the use of the 300-pen. bitumen ruled out almost completely the large volume of trade which had been done on the basis of delayed set. He could foresee the likelihood of a recommendation such as that made in the Paper being generally adopted, and he thought it would be in many ways a fitting conclusion to the work which had been done if it were recognized and used by engineers; but allowance must be made for the proprietary materials which had built up a good reputation so far, and also for those cases in which transport might cause a delay of some days before the material was laid on the road.

As he was privileged to take an interest in bitumen, he appreciated Dr. Spielmann's trenchant remark about the addition of bitumen to good tar; but he would emphasize the remarkable optimism of people who thought that the addition of 5 per cent. would have any very great effect upon the combination.

Mr. A. J. H. Clayton said he knew nothing about the preparation or laying of the coats described in the Paper, but certain points in connexion with them interested him from a more general point of view. One was the measure of failure of the carpets. It had been stated in the Paper that one way in which the carpets might fail was by the development of a smooth surface, which would result in skidding in wet weather. Perhaps the Author could say what standard was used, because if a carpet or any road surface developed a sideway force coefficient of less than 0·5 under ordinary

conditions it must be regarded as having failed to do its work, even if it lasted for 10 years more without breaking up. There was a tendency to regard a good surface as one which would last, even if it became as slippery as glass. Naturally the two qualities of durability and non-skid property tended to be antagonistic.

Mention had been made of the measure of traffic, and he was interested to learn that the measurement by tons was not satisfactory even from the point of view of measuring durability. It was certainly no good from other points of view. Perhaps from the standpoint of both traffic control and wear some simple classification might be adopted, such as heavy goods vehicles and omnibuses, light motor-vehicles, bicycles, and so on. The numbers of each would probably give a good indication of wear, and certainly would be more satisfactory from the point of view of studying traffic.

The traffic on the Colnbrook by-pass, although heavy for a road carrying the high-speed traffic of the country, was relatively light for towns, and it would be interesting to learn whether it was possible to extract from the results of the experiment any information as to whether the carpets could give a few years' life to bolster up some of the expensive surfaces which needed repair but could not, in the national interest, be repaired during the war; he referred to blocks that had rather gone to pieces and sets that had become uneven, or even the thicker bituminous surfaces.

Mr. J. C. Hamer said that one point which had particularly interested him in the Paper was the statement: "It is noteworthy that there is no support for the theory that the binder-content should depend upon the surface-area of the aggregate." It seemed to him, by the very nature of things, that if one mixed stone and sand and coated them with a film of binder there should be some relation with the surface-area covered. Taking as a very simple illustration, a wall painted with some form of paint, he was sure that the Author would not say there was no support for the theory that the binder-content did not depend upon the surface-area. It seemed to him that the truth of the matter was that the importance of the surface-area was masked by other factors. Extending his simple illustration, if one imagined a rough-cast wall painted with a binder and then folded over on itself and pressed together, it would be evident that two new factors were at once introduced. Firstly the film of binder was not of uniform thickness, and secondly the idea of voids had been introduced. He considered that those voids masked the importance of the surface-area. In *Figs. 2* and *3* there was a general tendency to show a minimum of about 20 per cent.; but he thought that that was, in reality, the composition of the densest mix, and that the voids acted as a kind of safety-valve for excess binder.

He assumed that he could regard *Fig. 1* as being representative of all the series of tests, that was to say, roughly it could be applied to the gravel-tar mixtures. He realized that it applied to gravel and bitumen, but he

was puzzled by the fact that the sand-contents were given as 19·5 per cent., 26·0 per cent., and 32·5 per cent., although the recommended specification for the sand-content of a gravel-tar carpet was from 23 to 27 per cent. It was an astonishingly small range of sand-content, and required some explanation. He wondered whether the Author had made an intelligent guess. He did not want to criticize him on that ground, because the practical engineer more or less spent his lifetime in making intelligent guesses, but he was rather surprised that the Author, as a research worker, should have adopted that course.

He was also surprised that it had been considered necessary to lay carpets with no sand in them. He rather wondered why the Author had not started the process of making intelligent guesses before the carpets were laid, with regard to the optimum quantity of sand.

Scientists had a special word for a guess; they called it a "working hypothesis." Would the Author agree that the specification given for the gravel-tar carpet was a working hypothesis?

Mr. E. R. Knight observed that the difference between the aggregates referred to in the Paper was fairly substantial. In addition to the difference in the mineralogical structure of the two aggregates, which obviously had some influence upon the adhesion of both tar and bitumen, one had been continuously polished, and that had possibly had some effect, even microscopic in scale, upon the structure of the surface, and had further modified the adhesion of the tar and bitumen. Reference had already been made to the fact that one aggregate was local and the other distant, and from that point of view the advantage was clearly with the gravel.

One point which had not been mentioned might profitably be investigated, not necessarily by an extensive series of tests but on a comparatively small basis, namely, the fact that one aggregate was rounded whilst the other was angular. Crushed gravel, as opposed to gravel as taken from the river-bed, would possibly show a wide difference in use and it might behave more like granite than river-bed gravel. He had seen small gravel literally rolled from the surface of concrete roads in London. Therefore it might be profitable to investigate the effect of using crushed gravel with the range of fillers and binders described in the Paper.

Dr. A. R. Lee considered that three novel results had emerged from the Author's experiment. The first was that with the granite aggregates very good carpets could be obtained with no sand; that was quite a new discovery. The second was that, as the fines-content of a particular series of carpets was increased, under the conditions of traffic on the Colnbrook by-pass there was no corresponding or significant increase in the binder-content required. The third was that, during the period of the tests, no advantage as regards the quality of the carpets through the addition of filler had been noticed.

The second result was of particular interest and bore very strongly on certain lines of investigation which had been in progress and which had

partly led up to the experiment described in the Paper. In the case of concrete roads one knew by mechanical tests in the laboratory what the quality of the concrete would be, and endeavour had been made to obtain a corresponding check on the quality of bituminous materials. A large number of different types of mechanical tests had been proposed for that purpose. Certain conclusions had been drawn from those tests, and the experiment described in the Paper had provided the first opportunity of checking them. He thought that all mechanical tests, as they had been carried out so far, would lead to the conclusion that the greater the quantity of fines in a particular mixture the greater should be the binder element in it. The difference between this result and the results from the road experiment were, in his opinion, due largely to the fact that, apart from road machine tests, the effects of traffic compaction were not simulated in the preparation of the laboratory specimens. The effects of weather were also omitted from the laboratory tests. He believed that one important result of the Author's experiment would be a revision in the procedure for carrying out mechanical tests.

With regard to the third result, the position was very difficult, because filler was always used in normal practice. He thought that it was a matter for more research. Dr. Glanville had mentioned a number of researches which had been carried out in the laboratory alongside the investigation described in the Paper, and one of those ought to be stressed, namely, the effect of weather. There was no doubt that when the carpets had been put down they looked very nice and lasted for a certain time, but they failed eventually. Presumably changes taking place within the carpet led to that failure, and they would appear largely within the binder. That provided a field of investigation which could profitably be developed and which would be pursued as more experimental carpets were laid.

Mr. J. S. Jackson observed that not much definite knowledge was available as to the use of local materials, and it was important that, if they were to be used, it should be in a manner which would ensure successful results. There was no virtue in failure, even with local materials, and under the stress of war-time conditions it was essential that the results should be satisfactory.

The Author's statement about the binder-content bearing no relation to the surface-area was, he thought, rather unfortunately put. It was obvious that normally there was an excess of binder, and it was equally obvious that when one began to fill the voids with filler one had to be careful how much bitumen was used in excess; otherwise two things would be trying to occupy the same space. On the other hand, it might be necessary to have a reasonable excess of binder when the more open carpets were used and when there was no filler to give support. The Author had made the very optimistic assertion that a successful carpet could be laid with $2\frac{3}{4}$ per cent. of bitumen. Mr. Jackson hoped that some restraining influence would be exerted in that connexion, because he

did not think that success would normally be obtained with $2\frac{3}{4}$ per cent. of bitumen.

The Chairman considered that the development of surface carpets had been a very marked feature of road engineering during recent years, and there could be no doubt about the usefulness of surface carpets, or the desirability of developing their use, in the interest of efficiency and economy in road maintenance.

Reference had been made to proprietary materials, and he thought that road engineers owed a great deal to the firms that had produced them; but those who were responsible for the production of proprietary articles would agree that the engineer should not only know what material he was using but also, if necessary, be able to manufacture and lay it himself.

One problem which had long confronted research workers in road engineering was that of correlating the results obtained in the laboratory with those achieved in practice under actual working conditions and over a period of years on the roads. Attempts had been made in research laboratories in America, Germany, and elsewhere to hasten the process. Three rotary machines of various diameters had been installed at Harmondsworth, at great expense, the last being 120 feet in diameter and comprising a tethered lorry; but, on the whole, the results had been rather disappointing.

The experiment described in the Paper was an attack on the problem from an entirely new angle. Credit was due to those who had taken part in devising and supervising the tests, and to the Author for bringing the subject to notice in such a pleasing manner.

The Author, in reply to Dr. Spielmann's suggestion that more details should be given of the traffic using the road on which the experimental carpets were laid, gave the following figures. A census taken in 1941 showed that the traffic in daylight (8.0 a.m. to 6.0 p.m.) consisting of :—

	Percentage by numbers.	Percentage by weight.
Private cars	43·1	15·3
Light vans	8·4	4·2
Lorries (and other heavy vehicles)	45·0	80·3
Motor-cycles	3·5	0·2
	100·0	100·0

The percentages by weight were based upon the vehicle—weights given on the traffic census forms of the Ministry of Transport. Bicycles were not counted.

In reply to Mr. Keep, it was true that gravels varied greatly in different parts of the country. In and around London the material was probably unusually difficult to use because the stones were generally rounded and of smooth texture. They therefore lacked the ability of crushed rock to hold together by interlocking and friction between particles. For that reason it was necessary to provide stability in another way, namely, by

the addition of sufficient sand to fill the voids more completely and, with its coating of binder, to hold the larger particles together by adhesion.

In reply to Mr. Floyd, it had been intended, in the early planning of the experiment, to use slag as an additional aggregate, but unfortunately it had been found impracticable to deal with more than two aggregates. The Author did not want to give the impression that, because good results had been obtained with granite, any special significance was attached to that aggregate compared with other crushed rocks. The results of other road experiments had led him to believe that good results would have been obtained if other aggregates, such as certain whinstones, quartzites, limestones, or slags, had been used.

With regard to the fatting-up of the carpets, he agreed with Mr. Aldington that that was sometimes brought about in practice through laying the thin carpet on a surface already rich in binder; but in the Paper he was referring to carpets that became rich through the traffic compacting the aggregate and forcing the binder to the surface.

Mr. Clayton's remark that the two qualities, durability and non-skid property, tended to be antagonistic, was true for that type of surfacing. The addition of fine material to a mixture tended to improve the durability, but beyond a certain stage it increased slipperiness. Although the individual carpets were too short to enable measurements of the sideway force coefficient at 30 miles per hour to be obtained, an estimate of the coefficient was made from surface-texture measurements and skidding measurements at lower speeds. He agreed that a coefficient of at least 0·5 at 30 miles per hour was desirable.

He did not know whether the thin carpets discussed would be successful as city streets. They were worthy of trials on bituminous surfacings, but good results on granite sets were not to be expected.

In reply to Mr. Hamer, he could only say that the results of the experiment showed no simple relationship between the surface-area of the mineral constituents and the binder-content. In a comparable series of carpets with increasing fines-content there was no corresponding increase in the optimum binder-content.

The range of sand-content for satisfactory gravel-tar carpets had, indeed, been found to be small. As mentioned in the Paper, however, the ranges of binder-content in that instance were not so extensive as they might have been, and it was possible that a slightly lower sand-content was permissible. Durable carpets had been formed with higher sand-contents, but they were considered too smooth. The proportions given in *Fig. 1* were those used on the asphalt plant where, for convenience, the stone-plus-sand was taken as 100 per cent.; subsequently the proportions were calculated as percentages of the total mix.

There was no doubt that a useful purpose was served by laying carpets containing no sand. Not only was it necessary, in an experiment of that kind, to cover as wide a range of composition as practicable, but also the

results from the granite-bitumen carpets indicated that such carpets were of practical value.

In conclusion, the Author wished to thank Dr. Glanville for allowing him to present the Paper.

Mr. W. H. Morgan, in proposing a vote of thanks to the Chairman, said that when the Road Engineering Section was formed the Council were anxious that it should become a really live and working Section, and very wisely chose Mr. Cook as its Chairman.

The Chairman observed that the success of the Section depended entirely upon its members, who, including home and overseas members, numbered about 2,000. The Section had started in rather difficult circumstances, as war had broken out almost as soon as it got into its stride; but it had been decided to go on, in spite of the difficulties, and he was sure it had been a great pleasure to the Members of the Council present that evening to see such a good attendance.

LECTURE ON

"Engineering Economics, Organization, and Aesthetics."

Delivered by

Sir CLEMENT HINDLEY, K.C.I.E., Past-President Inst. C.E.
At the University of Cambridge on the 17th October, 1941.

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PART I. INTRODUCTION.

ON 15th May, in the year 1894, the new engineering laboratories and workshops in Free School Street were opened by Lord Kelvin. Perhaps we did not fully realize the historic importance of the occasion or our privilege in being present and in listening to his address. He was well known to us as one of the greatest living scientists and an engineer whose practical contributions to the progress of Engineering Science had received world-wide recognition. No doubt we were impressed by the fact that our engineering laboratory at Cambridge was of such importance that this great man had come to see it inaugurated. But it has to be confessed that the only real impression that remains in my mind is the venerable appearance of the central figure of the ceremony, his long, flowing white beard and his penetrating blue eyes. Long study of our stained glass windows during the hours of compulsory chapel enabled us to recognize the resemblance between Elijah and Moses and the great Victorian scientists, just as the eminent Victorian Divines of our acquaintance appeared to follow the tonsorial customs of St. Peter and the Apostles.

It is unfortunate that we have no verbatim record of the address which Lord Kelvin delivered, nor of the speech which must have been made by Professor Ewing in opening the ceremony. Some fragments, however, were recorded and I find that Lord Kelvin spoke of the direct evolutional connexion between the theoretical mechanics and pure mathematics of his day at Cambridge and the establishment of a department in which their principles found application and verification. He spoke with authority because almost from the time when he entered Peterhouse as an undergraduate 53 years before, he had himself played a great part in that evolution.[1] He affirmed that "true education consists in providing the

[1] Kelvin entered Peterhouse in 1841, was second Wrangler and Smith's Prizeman in 1845, and was appointed Professor of Natural Philosophy at Glasgow in 1846, a post which he held until 1899.

most efficient means for the equipment of persons for the battle of life." Kelvin must have had much close discussion and argument with Ewing about the functions and scope of the engineering curriculum, and we may assume that he had in mind the scheme which Ewing was then developing and which formed the basis of the Engineering School as we now know it.

That date in May 1894 was a memorable occasion for other reasons, because it coincided with the first Mechanical Sciences Tripos examination and thus set the seal on Ewing's first three years of strenuous work as Professor of Mechanics and Applied Mechanism. In this short period this "Patron Saint" of the Cambridge Engineering School, as he has been described by Professor Inglis, had, with remarkable and outstanding energy, succeeded in establishing engineering education on a solid foundation amongst the older faculties of Cambridge. He had given it a home of its own almost under the wing of the Cavendish Laboratory, and had persuaded the University authorities to accept engineering as a subject fit to rank with the older media of education which had for so long been traditional at Cambridge. There can be few survivors now of the great controversy which must have raged amongst the hierarchy of the University over this decision. Ewing must have had a hard fight, but not many would now question the benefits which have accrued both to the University and to engineering science itself from this great step forward.

I can again quote from the record of Lord Kelvin's address, in which he is no doubt paraphrased as having said: "The establishment of an Engineering School at Cambridge has already drawn to the University a number of earnest, hardworking students, who, but for it, would not have joined the University. Their presence cannot but benefit the whole University." I find from the University Calendar that seven students succeeded in getting into the class list of the first Tripos in 1894. There were thirteen in 1895 and eleven in 1896, so that the whole number of students at that time could not have been more than thirty or forty. During the period that has elapsed, the enormous progress made is only faintly indicated by the fact that in 1938 the total number of students who had to be provided for was just short of six hundred (582).

For half a century the Engineering School at Cambridge has shown a continuous and vigorous growth. Not only has its influence been felt in widening the boundaries of the field of engineering education, but in the greater field of engineering science itself, notable contributions have been made by the application of the scientific method to problems which engineers had formerly to solve mainly by empirical methods. It would be difficult to estimate the effect on the University of the introduction of this new instrument of education into the midst of its traditional modes of thought, but it is more with the effect on the engineers who are trained here that I am concerned to-day and it is instructive to return again to Lord Kelvin's definition of true education.

How far in fact does the present curriculum equip young engineers for the battle of life?

This is a question which has been much canvassed amongst many of the older members of the profession and particularly the Council of The Institution of Civil Engineers. Ewing's scheme of education which has made Cambridge outstanding amongst the engineering schools of the world, has always had a special attraction for the governing body of my Institution, because it seems most nearly to fulfil the requirements laid down in our Charter for the equipment which an engineer should have in order to carry out his duties and responsibilities. The Charter defines the work of the civil engineer as that of "directing the great sources of power in nature for the use and convenience of man." The Engineering School at Cambridge has always retained its character of imparting fundamental knowledge and encouraging only a limited amount of specialization. Other universities and engineering schools have not always followed this ideal—a fact which in my opinion has contributed much to disunity amongst the various branches of the engineering profession. The late Lord Rutherford translated the prescription laid down by our Founders into a simpler and more modern form. He affirmed that the stately words of our Charter really meant the same thing as the modern definition of an engineer—"a man who can do with one dollar what any fool can do with two." The process of thought between the one definition and the other, however, covers more than a century of development and expansion of the engineer's sphere of work, and it is legitimate to question whether in the education and training which is imparted by the present curriculum there is not, perhaps, a tendency to disregard human reactions to and on the engineer's work.

Modern developments, both in engineering practice itself and in the world at large, demand that an engineer must be not only a technician but also a man of business and a man of affairs. For an engineer to carry out his work successfully and to take his place as a man of influence in human affairs, it is essential that he should acquire some knowledge of the fundamental principles which govern his relations with his fellow human beings. It is quite obvious that the time available in a normal engineering course of study is insufficient to enable the student to be a complete master of all the subjects with which he will have to make himself familiar in the course of his further training and experience. But just as the Engineering Tripos itself has a general and fundamental character on to which has to be grafted much practical and special experience later on, so in the realm of human relations there is much which is fundamental.

It would not be too much to say that in carrying through an engineering project probably 75 per cent. of the directing engineer's time, energy, and brain power are absorbed in overcoming human difficulties and the remaining 25 per cent. in solving material and physical problems. The engineer will find that the forces represented by human ignorance, prejudice,

stupidity, and cupidity are frequently of the same or even a higher order of magnitude than the great sources of power in nature which he is trained to direct. The mental equipment necessary to deal with these human problems is, under the present method of education, left to be acquired by the engineer in the course of his practical experience, often by many years of trial and error, in which error frequently predominates. It is our firm belief that the time has come for establishing some instruction in the fundamental principles which underlie these human relations and some guidance as to the way in which the human problems involved in the engineer's work are to be solved.

In endeavouring to define something of these fundamental principles in a form which, within the practical limits of time and opportunity, might be included in an engineer's education, it is necessary to analyse the character of the human element in engineering problems. The relations of an engineer with his fellow human beings in executing his work fall into three main categories: firstly his relations with the managers, directors, administrators, and politicians who direct his work or wish to make use of his art; secondly, his relations with his fellow workers, mental or manual, who compose the organization with which he carries out his work; and thirdly, his relations with those whose lives and environment are affected by the result of his work. His relationships in the first of these categories will be bound up with the economics of engineering design and construction. The second involves the organization of engineering works; and the third category, although it might be held to cover a vast range of political and sociological problems, must be again simplified for my present purpose and focused particularly on the aesthetic treatment of design and the preservation of amenities.

These simplified aspects of the much larger problem have served, in the opinion of the Council of The Institution of Civil Engineers, to form a suitable basis for the additions which they would wish to see made to the University course of study. They have accordingly asked the University authorities that these subjects shall be introduced by stages into the curriculum, with the hope that in the future they may indeed become an integral part of the Tripos itself.

Possibly some apology is needed for making this attempt during the present troubled times, but we are so much concerned with the work which will fall to engineers in the great era of development which must take place when victory in this war is achieved that we feel that it is imperative to make a beginning at a time when engineers who are to come into this heritage are undergoing their training. We are most grateful to the University authorities for their ready acceptance of our proposal, and our thanks are specially due to the late Vice-Chancellor and to Professor Inglis for the patient and sympathetic way in which they discussed with us our objects. It has now been arranged that this somewhat drastic surgical operation shall be started by the application of a simple treatment, not

of the nature of an anaesthetic, but rather as an initial exploratory operation, and to begin with a series of lectures in which engineers and men of affairs will give such instruction from their own experience as they consider appropriate to those subjects.

It is now my duty to explain in more detail how these three subjects appear to develop themselves, regarding them as suitable additions to the engineering course of studies.

Part II. The Economics of Engineering Projects.

One of the essential differences between the work of the pure scientist and that of the engineer lies in the fact that the scientist sets his own problems and makes his own conditions, whereas the engineer's problem is set for him and the conditions are generally inexorable and indeed form the ready-made boundaries of his problem. The education which an engineer receives gives him the means of carrying out his work within the conditions of the time, space, and material configuration of the problem. He must design for known requirements of strength, stability, and durability with materials whose physical properties are known or can be determined to the greatest possible degree of accuracy. There is, however, one condition governing his work which he will find is sometimes of more compelling influence than the conditions which by his normal education and experience he will be able to master. That condition is the economic result of his finished work. Put shortly, the problem may be stated in this way: "Having spent so much money, what is the effective return to the promoters of the project?" In the large majority of cases where an engineer is entrusted with the design and construction of a project, the promoters will only undertake the work if they can see a prospect or indeed a certainty of earning a substantial return on the capital expended.

In these days of changing values of money and of vast expenditure on what may be classed as unproductive work or, at any rate, unproductive in the immediate commercial sense, it may be almost an anachronism to talk of capital and the return on capital. Instead of leading us to theorize or speculate on the effect of war on national or individual wealth, the kaleidoscopic changes in all our standards should lead us as engineers to a clearer vision of what in fact constitutes the cost and the value of an engineering work. For the engineer the cost of an engineering work is not so much the cost as expressed in pounds or dollars as its consumption of labour and materials. Man-days and weight or volume of materials are the units with which the engineer works. Prices of both expressed in currency are made for him by others and are conditions over which he has very little control. Over quantities, however, he is the master; and it is in exercising his control over the quantity of labour and materials consumed in carrying out his design that his success or failure lies.

In general he will find it necessary to adopt the most economical design

which fulfils the requirements of the promoters. It is true that there are many occasions where conditions other than the purely economical may circumscribe his freedom to design. The promoters, for instance, may prescribe the use of certain materials or a certain kind of finish which are not the most economical. And again we shall see in dealing with the problem of aesthetic treatment that the requirements of the promoters may be an important influence on the adoption of one out of many alternative designs. There is a further condition, the existence of which may form a powerful factor in determining design, and that is the length of life which is expected for the structure or the work. At the present moment so much of the engineer's work is devoted to structures and machines which are expected to function for a limited period, generally called "the duration", that it is perhaps difficult to visualize the importance of relating design to ordinary peace-time standards of durability. The point which is to be emphasized is, however, that the engineer can and should exercise a powerful influence by his planning, his choice of materials, and his design on the production of an economically sound result.

In the future there will be no room for extravagance in design or construction and every penny spent should be made to purchase full value in utility. The engineer must accordingly be equipped not merely with the latest knowledge of available materials and the scientific solution of design problems, but must also have at his disposal the necessary knowledge and technique for assessing the economic result of his completed work. With this technique and the experience gained by using it, he should be able to act as a valuable guide to those responsible for launching and financing the project. Further, his judgment would be valuable in assisting to form decisions on the necessity for various parts of the project and on the relevancy of details to the ultimate objective.

A further aspect of this matter is the reaction of these economic considerations on the design itself. An engineer, when evolving his design, has to consider a multiplicity of designs before arriving at the most economical one. Thus in designing a big building he may have to consider whether he will construct it with a reinforced-concrete frame, steel frame, or other method of construction. Before he can make a correct decision he must be able to estimate with fair accuracy the cost of the various types of design. To do this he must have at his disposal a sufficiently accurate knowledge of how to prepare estimates of costs. He will no doubt have the assistance of quantity surveyors and expert cost accountants, but nevertheless if he is to retain his directing powers he should have a sufficient acquaintance with these subjects to enable him to appreciate the results.

Similarly, in designing a factory an important consideration is the spacing of the columns and supports in order to accommodate the plant which is to be used. He must accordingly be in a position to furnish with reasonable accuracy approximate estimates of the various alternative layouts which may be required by those who have the business of arranging

the plant and the sequence of processes in the factory. In general the engineer will find it necessary to acquire some knowledge of the uses to which his structures are to be put, and the ideal situation for him to achieve would be one where he had sufficient knowledge of these purposes to enable him to discuss questions of layout and design on equal terms with the promoters and users of his finished work.

An instance of this may be drawn from my own experience in connexion with the construction of new railways and branch railways in India for the development of areas where communications were inadequate. In endeavouring to build up a programme of survey and construction which should reach at its peak the production of approximately 1,000 miles of new railway per annum, we were given a limiting financial condition that no project should be undertaken which did not provide reasonable expectation of earning 6 per cent. on the capital cost. To fulfil this condition it was necessary for the engineer to obtain all the facts which might be expected to influence the business which the new line of railway would attract. His survey, therefore, was not merely an engineering job consisting of getting the best and most economical line through a specified piece of country; he had also to consider the class of traffic that would be carried, and for this purpose statistics had to be obtained of the productive capacity of the area, its population, and to some extent the habits and customs of the people. Knowledge of results obtained in similar tracts of country would be available to him and he would have an expert staff capable of assessing the effect of varying conditions as regards production, commerce, and local trade on the future traffic on the railway. It will be obvious that this traffic survey, as it was called, was a very potent factor in enabling the engineer to arrive at decisions about the location of his line. He would, for instance, have to decide whether an easy river crossing was more desirable than keeping his line in proximity to a local market or place of pilgrimage. Further, he would have to consider the effect of constructing the railway to its selected alignment on the working expenses and operational costs generally. For this purpose he had to have at his disposal a fairly good working knowledge of the costs of operation as influenced by gradients, curves, and stopping places. In his final report and estimate it was necessary for him to explain in considerable detail the basis of the selection of his alignment and the expectation of traffic income, with supporting statistics and facts.

This instance shows that the simple and straightforward methods which the engineer is usually taught to apply to railway alignment only cover a fraction of the problems with which he is faced when entrusted with such a task as I have described. It is not possible or desirable that the engineer placed in such a position should try to deal with his specific engineering problem in a watertight compartment while the other economic considerations are dealt with by so-called experts, because it is notorious that such people do not usually adopt the methods of thought which are in-

culcated in the engineer by his upbringing, and unless he is able to influence their methods he may find that his design, that is, the alignment of his railway is influenced by inaccurate deductions from imperfectly ascertained facts. In such circumstances the engineer no longer remains the complete master of his design, but has frequently to subordinate technical considerations to the opinions of those who are perhaps more concerned with the commercial result than with the technical excellence of the project.

It is necessary to bear in mind that in general the engineer's influence on the promoters and his power to convince them of the suitability of his design depend greatly on the accuracy of his estimating and on his power to appreciate the objects of the promoters and the economic basis of the use to which the work is to be put. While the engineer is pledged never to sacrifice strength or stability to financial considerations, it is equally his duty to see that finance is not sacrificed to over-caution and the "factor of ignorance" in design.

PART III. ORGANIZATION OF ENGINEERING WORK.

The mental equipment necessary to create a satisfactory organization with which to carry out an engineering work is difficult to define. You will hear a man spoken of as being a good organizer or as a man who has no idea of organization. Again you will find men who make it their profession to be organizers or re-organizers of business concerns. But although there are some who can rightly claim to have the necessary mental equipment and experience to be masters of this art, there are far too many whose knowledge is of the text-book variety and whose few successes are widely advertised, but whose miserable failures are relegated to the background.

It is largely because business management and organization has come to be looked upon as something that can be learnt from a text-book or picked up from lectures or even correspondence courses that the science itself—for indeed it is worthy to rank as a science—has been in danger of becoming discredited. You can still raise a hot controversy on the question whether organization and business management can only be acquired by practical experience after education or whether it can be taught in a college or university as part of a man's education. The truth, as often in such controversies, lies between these two extremes, because the science of management and organization has been so far developed as to have established certain fundamental principles and methods which, while dependent on and arising from the almost infinite variety of human proclivities and appetites as well as human powers, both bodily and mental, can be used as a basis for the organizing of almost every variety of human enterprise. The fundamental principles are often obscured by the technique which has been established by the apostles and exponents of this science and the proliferation of methods by which it is assumed an organization

can be synthesized is rapidly becoming a recognized medium of education. So long as this great body of teaching and doctrine is kept in its place as a categorization of method and is not looked upon as an end in itself, it is all to the good that research, experiment, analysis, and codification should go forward. It is, however, a profound mistake to suppose that the acquisition of this knowledge can of itself produce a good and successful organizer. The inherent quality of leadership cannot be produced in a human being by the acquisition of this book knowledge alone.

The two extremes which have to be avoided by the engineer or those who are responsible for educating him, are on the one hand the idea that an engineer cannot organize his work successfully without being a complete master of this new body of knowledge and on the other hand the belief that organization is only just common sense and that an engineer by his technical training can, out of his head and by applying his well-learnt scientific method, produce and manage the organization necessary to carry out his work. The grounding in scientific method will carry him a long way, but just as in the application of scientific method to engineering itself a knowledge of the fundamental physical characteristics of materials is necessary, so in applying it to the processes of a human agency, knowledge is required of the characteristics and capabilities of the human units that compose the organization.

It must not be overlooked that the successful organization of a construction job depends on a vast number of factors other than the welding together of a human team. The engineer must have the capacity to acquire knowledge of the proper and appropriate plant and equipment and its effective use, and this implies that he must not only keep abreast of developments in plant so that he can choose the most appropriate for his job, but he must in fact be capable of influencing, even if he does not actually direct, the evolution of new and better mechanical means to meet the requirements of new problems in construction.

The engineer must also make himself master of the methods, statistical and otherwise, by which progress is watched, and conversely he must be able so to model or re-model from time to time his organization and scheme of operations as to produce the most effective rate of progress and the largest out-turn per unit of human labour. He must also be able to study and appreciate the relative productive values of machine and man so that there is a proper balance in operation between running costs and overheads inherent in the use of machines and the expenditure on human labour. His operations must be ordered so that his machines are not kept idle waiting for human labour or human labour kept idle waiting for machines.

All these subjects, and more, must be available to the engineer if he would be a successful organizer. They form the tools by which he can secure efficiency, economy, and exactness in getting his work done. He will either acquire the requisite knowledge himself or he will have the collaboration of those who have become expert. But here again he cannot expect

to become and remain the master of his work unless he possesses the fundamental knowledge of human affairs on which these branches of knowledge are based.

But I must return to an endeavour to simplify the problem of organization, and here my own experience leads to the conviction that it is only when certain very simple principles form the basis of an organization that the maximum efficiency and economy are reached. Inefficiency and waste can generally be traced to a neglect of these simple principles. They may be briefly described as follows. The efficient organization is one in which

(1) every member is bearing a full share of the work according to his capabilities and experience; no one should be worked beyond his capacity; no one should be idle;

(2) there is a clear line of responsibility from the administrative head, through the various stages of devolution of authority down to the executives and operatives;

(3) there is a clear demarcation between functions throughout the organization, and authority must be coupled with responsibility at every stage;

(4) no person at any stage in the organization in an executive or administrative capacity has to deal daily with more than five, or at most six, persons responsible to him for instructions.

If any justification is required for this basis of efficient organization, it will be found in accepted military practice where the most efficient organization has had to be evolved under conditions where the price of inefficiency is death and disaster. There are many who, in peacetime, are inclined to put military organization in a category by itself as a specialist organization designed for a special purpose. It is sufficient refutation of this view to point to the confusion and chaos which occur when peacetime organizations have to be re-modelled to meet the conditions which we are now experiencing of a nation at war.

But I may add that in my own experience I have applied these principles to the wholesale remodelling of the organization of the Indian State Railways with a total man power of nearly half a million, and have proved that very great increases in efficiency have resulted. Incidentally I also proved that a state-directed organization based on these lines can be made an efficient commercial undertaking, contrary to general belief in this country.

Part IV. Aesthetic Consideration in Engineering Design and Construction.

We have been considering the human problems of the engineer from the aspects of economy and efficiency We have now to consider a third human problem, namely the effect of the finished work on the people whose lives and environment are affected by it. This broad definition includes, of course, all the problems which are raised by the impact of

engineering science and the scientific method on the current life of the people. Many of these problems fall to be solved by others than engineers, although they can by no means be ignored by the engineer in his work. It is necessary for the engineer to recognize from the very outset of his career that on the one hand his work will be influenced profoundly by sociological and political considerations, and on the other hand that he must make himself acquainted with the fundamental aspects of these considerations if he is not to occupy permanently a subordinate position in the community. This wider field I must leave to others to expound. For the present I wish to confine our consideration to the special problem of the aesthetic treatment of engineering structures and works.

This is largely a psychological problem and arises out of the fact that, whether by heredity or acquired habits of mind, every human being has within himself an individual standard of widely varying quality by which he judges the appearance of a structure or completed work. It is perhaps a fortunate fact that this standard cannot be reduced to any scientific formula, because it is in essence a quality of the individual. It has, however, certain features which tend to integrate themselves on a common basis in mass psychology which can be described as public opinion, fashion, or schools of criticism. We cannot define beauty in simple terms, nor can we set rigid standards for the engineer to work to in his designs. There are those who believe that it is possible to codify them and will endeavour so to do, but for my part I believe that such attempts result in the destruction of the ideal which is aimed at.

The question, however, which we have to look at is : " Can an engineer design a thing of beauty ? " I am not going to attempt to answer the question specifically, but it is a question which will continue to be answered in the affirmative and in the negative so long as engineers continue their work. It is our object so to influence the training of the engineer that there will in future be more cases where the question can be answered in the affirmative than there are at present. My present desire is to emphasize that this is a problem, the existence of which must be recognized by engineers as one which cannot be relegated to others for solution. There is no doubt whatever that the individual human mind and public opinion are influenced very greatly by the appearance of a structure and to such an extent that if aesthetic treatment is altogether disregarded there is a definite reaction in the public mind not only against the structure itself, but against those who have caused its erection, those who have designed it, and the processes or purposes to which the building is put.

It has been well said by Dr. Faber [1] that " structures exert an important influence upon humanity, tending to nobility and joy in life if they are noble and beautiful and to meanness and misery if they are not." And again [2], "structures reflect the character of their time and civilization, being

[1] Journal Inst. C.E., vol. 16 (1940–41), p. 141 (April 1941).
[2] *Ibid.*, p. 151.

dignified and beautiful when the life of the period was lived with dignity and being mean in an age of sordid money-grubbing." We want the engineer to be able to play his part in producing a beautiful and noble environment, and never was it more necessary than in the immediate future when the engineer will have such an influential contribution to make in re-planning and re-modelling the physical surroundings of the people, whether in town or country, in the period of development after the war.

We cannot, however, make a man an artist unless he is born with certain qualities. In general it may be said that a man is induced to become an engineer by reason of certain innate characteristics which it is customary to think are incompatible with the characteristics of an artist. Some there may be fortunate enough to be both artists and engineers, but the probabilities are against such a coincidence happening very frequently.

How, then, shall we ensure that the engineer avoids producing ugly and repulsive structures? I cannot be content to believe that a structure efficiently designed to fulfil certain functions must of necessity be ugly and can only be made beautiful by some overlay of art. This belief is widely held and has resulted in the process of calling in the architect or artist to correct the ugliness, just as a doctor is called in to cure a disease. The architect himself in such a case is at a disadvantage, because the engineer's structure ties his hands and circumscribes his genius so that at the best he can only produce a kind of ornamental skin to the structure. Much of our modern architecture is in fact only skin deep as the result of this process.

And further, I am not content to believe that aesthetic treatment necessarily increases costs. It is true that it may do so if the promoters insist on special treatment or special materials or finish. But in my view the result of the engineer's work, if he has designed with a correct regard to functional requirements, if he has adopted the most economical structural design, and if he has paid attention to the selection of materials suitable to the environment of his building, will tend to satisfaction in those who see it and be regarded as, at any rate, not unbeautiful. While, therefore, we cannot attempt to make every engineer an artist, and while we can perceive the futility of trying to make every engineer his own architect, we can at least give some grounding in the requirements of aesthetic treatment, so that the engineer can avoid offence to human susceptibilities in his designs and, which is perhaps more important, can appreciate the necessity of collaboration with architects who have made the design of beautiful structures their life work.

There can be no doubt that there is a great scope for team work as between architects and engineers. Too much stress has sometimes been laid on attempts in public discussions to solve the problem whether the architect should be subordinate to the engineer or vice versa. In practice the best work has been done by close collaboration and team work, and to make this more and more possible it is very desirable that in the education

period the engineer should be given some understanding of the basis of aesthetic treatment, while, on the other hand, the architect should be taught sufficient of the scientific basis of design to enable him to appreciate the engineer's work. I hope that the process we have now set in motion will be continuously directed to this end.

Conclusion.

At an earlier stage I ventured to express some apology for attempting an addition to your studies in these times of trouble and general upheaval. But if I have successfully performed the task I set myself there is, perhaps, no need for such an apology.

We are in the midst of most tremendous events and on the threshold of changes in world order of greater import than any in the history of mankind. We cannot stand aside and merely watch these things happening, and you who are now being trained as engineers must prepare by every means open to you for the responsibilities which will fall on you in a greater degree than perhaps on any other section of the community.

Warfare, which is in essence mechanical warfare, gives an enormous stimulus to all scientific and technical progress. Developments of a kind which formerly took years to establish are now accomplished in months or weeks. The world will emerge from this ordeal richer than ever before in conquests over the forces of nature, and it will be for engineers to see that mankind—that is every man in every land—has his fair share of the results of these conquests.

If in the past we may have somewhat neglected the humanities and have relied on the acquisition of technical power without ensuring that it is directed to the use and convenience of man, let us determine that in future we will be not only worthy members of a learned profession, but also worthy citizens in a state whose affairs are influenced and directed by scientific truth.

Student's Paper No. 973.

"Concrete and the Resident Engineer."

By Dermot Francis Wilkin, B.Sc., Stud. Inst. C.E.

(*Ordered by the Council to be published with written discussion.*)[1]

Introduction.

During several decades more and more use has been made of concrete in carrying out engineering works. It is being largely used instead of steel in bridge construction; replacing masonry and brickwork in buildings; whilst more roads are being constructed of concrete in place of tarmacadam or asphalt. This increased use of concrete is imposing more responsibility on the resident engineer, who, instead of having the materials required for the construction of the work delivered to him on the site, already manufactured by a carefully-controlled process, as in the case of steel, bricks, and asphalt, becomes in effect the manufacturer, and has to see that the careful control which is maintained in, say, the manufacture of steel, is exercised, so far as possible, on the site in the proportioning and mixing of his concrete.

The resident engineer's task of maintaining this careful control, and keeping to the specification to produce the dense and strong concrete required, is rendered more difficult by the fact that the composition of the raw material with which he is supplied is usually of a very variable nature; it varies not only in composition from load to load, but also in bulk from day to day, depending upon the weather.

The object of this Paper is therefore to set out and explain a type of specification for the concrete and the practical work necessary on the part of the resident engineer to keep to this specification in spite of such variations in the aggregates supplied, so as to produce a workable concrete of maximum strength and density, containing only sufficient cement to give the required strength.

The Specification.

Specification Clauses.

The following are suggested clauses specifying the aggregates and the proportioning of the mix.

[1] Correspondence on this Paper can be accepted until the 15th March 1942, and will be published in the Institution Journal for October 1942.—Sec. Inst. C.E.

Fine Aggregate.—The fine aggregate shall consist of crushed stone or natural sand, as may be approved. It shall be free from injurious amounts of clay, vegetable, saline, and other foreign matter. The Engineer may require the sand to be washed. The size shall be such as to pass a $\frac{3}{16}$-inch clear mesh, and graded down to as fine as may be approved. Not more than 10 per cent. should pass the No. 100 sieve and the silt should not exceed 5 per cent.

Coarse Aggregate.—The coarse aggregate shall consist of broken stone of good tough texture, free from dust, surface, and weathered material, to the approval of the Engineer. The stone shall be graded from the largest size specified for the particular class of concrete and shall be retained on a $\frac{3}{16}$-inch square clear mesh. Flat or elongated pieces of crushed stone shall be avoided, and the deliveries must be uniform, and not the product of several different quarries.

Proportioning of the Concrete.—Cement shall be measured by weight, and the fine and coarse aggregates by volume, separately. The aggregates shall be tested for grading, etc., by the Engineer's representative, and the ratio of fine material to coarse shall be fixed from time to time so as to give a dense workable concrete with the minimum water/cement ratio, so as to produce a definite weight of cement per cubic yard of concrete in place. A daily check will be made to ensure that these proportions are correct, and for this purpose suitable returns shall be rendered daily to the Engineer's representative. Attention is directed to the effect of bulking of sand when damp. Boxes of sizes corresponding to the proper quantities of cement and aggregate as above, or as determined by the Engineer's representative from time to time, shall be used for gauging the material.

The specification shall also give details of the quantities of cement and the size of stone for the several classes of concrete, on the following lines :—

Class A concrete :	550 lb. of cement per cubic yard in situ—max. size of stone $1\frac{1}{2}$ inch						
Class B	,,	450	,,	,,	,,	,,	,, $\frac{3}{4}$ inch

Some engineers prefer to specify the weight of cement as a function of the weight of aggregate and others as a function of the volume.

The foregoing clauses deal only with the aggregates and proportions, as clauses dealing with cement, water, mixing, deposition of the concrete, vibrating, etc., are not germane to this Paper. The various sand gradings and stone sizes used later in this Paper were not supplied to conform with the clauses suggested above.

The Practical Work.

Fixing the Ratio of the Aggregates.

In order to fix the ratio of the aggregates as mentioned under the clause for proportioning the concrete, it is necessary for the Engineer and resident engineer to decide the type grading at which to aim. Type gradings such

as those of Taylor, Thompson, and Smulski [1], or of Professor H. N. Walsh [2], Assoc. M. Inst. C.E., are available. In this Paper the Taylor, Thompson, and Smulski curve has been selected, but any other could be substituted with little difficulty.

Weights of Aggregates.

The resident engineer must now work out the volume weights of the aggregates available. This may best be done by the method described in British Standard Specification No. 812. The method, in brief, requires a cylindrical container of $\frac{1}{10}$, $\frac{1}{2}$, or 1 cubic foot nominal capacity, depending on the size of the aggregate. Its actual volume is checked by weight when full of water at 20° C. This measure is then filled with the aggregate (previously dried and thoroughly mixed) by tamping in three layers, and finally striking off level with the tamping rod. The net weight of the aggregate in the measure is then determined, and the volume weight is deduced from the capacity of the measure.

The following results were obtained for the aggregates referred to in this Paper :—

Sand A	112 lb. per cubic foot.
Sand B	106 „ „
Clean $\frac{3}{8}$-inch screenings	90 „ „
Clean $\frac{3}{4}$-inch screenings	95 „ „
$1\frac{1}{2}$–$\frac{3}{8}$-inch broken stone	105 „ „

Mechanical Analysis of Aggregates.

The apparatus necessary for carrying out the mechanical analyses of the aggregates consists of a set of sieves of the sizes given in Table I, and

TABLE I.

Fine wire mesh	0·006 100	0·0116 52	0·0236 25	0·0474 14	0·0949 7	Inch B.S.S.No.
Medium wire mesh or perforated plate	$\frac{3}{16}$	$\frac{3}{8}$	$\frac{3}{4}$	1	$1\frac{1}{2}$	Inch.

a balance or scale capable of weighing to 0·1 per cent. of the weight of the test-sample.

To carry out a mechanical analysis of the sand or stone delivered on the site, a sample of about 2,000 grams of sand (or 4,000 grams of stone) is taken from the heap of aggregate. The selection of this sample should

[1] F. W. Taylor, S. E. Thompson, and E. Smulski, "Concrete Plain and Reinforced." Chapman and Hall, London.

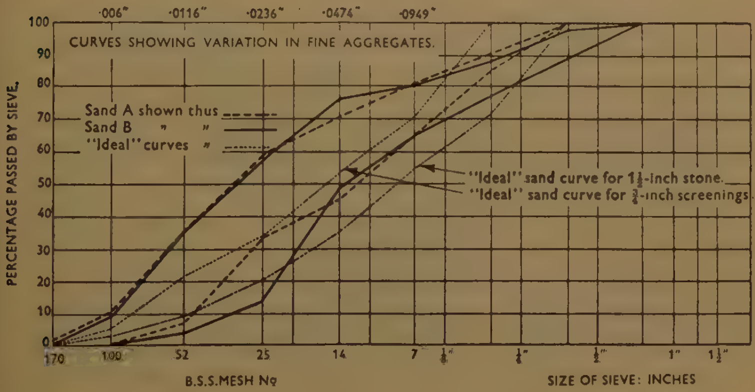
[2] H. N. Walsh, "Aggregate Grading, and Design and Control of Concrete." Inst. C.E., Northern Ireland Association (1936–7); 37 pages (December 1936).

be made with care, in order that it may be representative; this is best done by the method of quartering, in which the aggregate is spread about 6 inches thick on a board or platform, and is then divided into four equal parts, one pair of opposite quarters being discarded. This is repeated until a sample of approximately the required size is left.

If the sample is damp, it must be thoroughly dried before the required 2,000 grams or 4,000 grams is weighed. This sample is now passed successively through the set of sieves, starting with the largest size necessary. Sieving is continued until not more than a trace of material has passed after 1 minute. Material smaller than ¾ inch must not be helped through sieves.

The material which has passed the smallest size of sieve is put in the scale-pan first and weighed, the result being entered in the "Grams passed"

Fig. 1.



column of the Grading Analysis Form, of which a specimen is shown on page 74, *post*, opposite the size through which it has passed. InExample 1, 192 grams passed the No. 100 sieve; the contents of the No. 100 sieve are then added to that already in the scale-pan, and the resulting weight, 532 grams, is entered opposite the No. 52 sieve, it being the total quantity passed by this sieve; the process is continued until the total quantity of the sample is returned to the scale-pan.

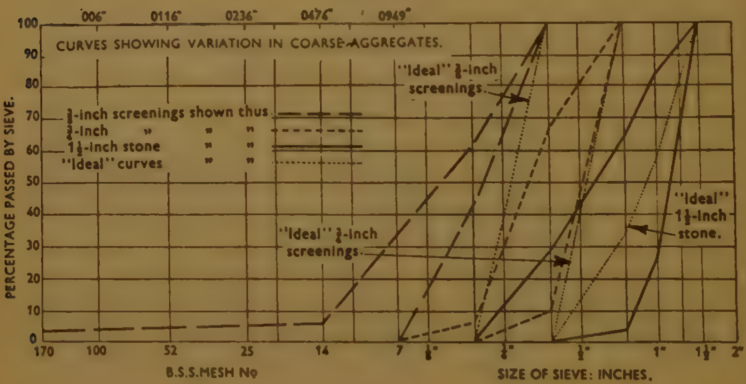
By converting these weights into percentages of the total, the results in the "per cent." column in Examples 1 and 2 are obtained. In this column the results are in the form required for use in proportioning the mix, and also for recording the results graphically, if required, as shown in *Figs. 1* and *2*, which are the curves for various aggregates.

As mentioned in the introduction, these grading curves (*Figs. 1* and *2*), show very clearly the variations in both the fine and the coarse aggregates supplied. It will be observed from the curves in *Fig. 1*, that in sand A there is a maximum variation of 26 per cent. in the quantity of material

passing the No. 14 sieve; and that in sand B the maximum variation is about 43 per cent. passing the No. 25 sieve. In the curves for stone (*Fig. 2*) it will be seen that here also there are large variations: the 1½–¾-inch stone varies by as much as 60 per cent. passing the ¾-inch sieve, and the ⅜-inch clean screenings vary by 57 per cent. in the quantity passing the ⅜-inch sieve, when actually nothing should pass through this sieve. It should be pointed out that the extreme examples showing a large variation have been chosen deliberately; average deliveries are usually found to be more uniform. The dotted curves shown in *Figs. 1* and *2* represent the "ideal" gradings for the three sizes of stone and the two types of sand.

Should the fineness-modulus of the stone or sand be required, it can easily be found from the grading analysis, as shown in Examples 1 and 2

Fig. 2.



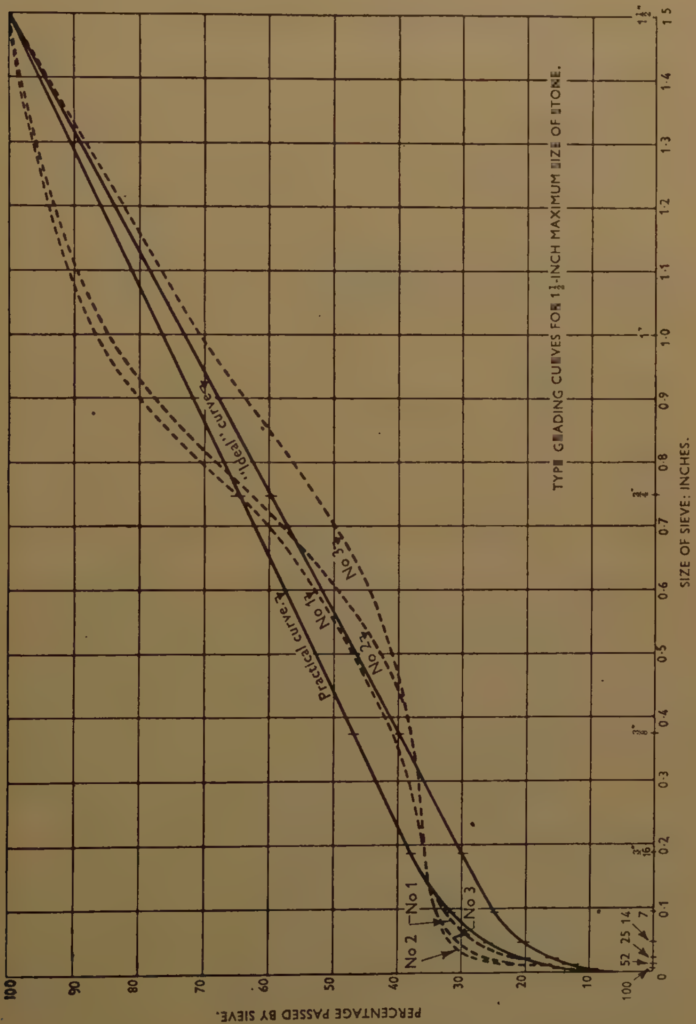
under the heading "Fineness-modulus." The percentage passing each sieve is merely subtracted from 100 and the difference is set down opposite the sieve-size. These percentages retained on the sieves down to No. 100 are then summed and divided by 100, when the quotient is the fineness-modulus. In the examples given, the sand has a modulus of 3·0 and the stone has a modulus of 8·08.

Proportioning the Mix.

With materials varying as indicated above, it is essential to have some means of proportioning the several materials so as to secure compliance of the mixture with the required type-grading. The type-grading used to find the ratio of the aggregates is taken from Messrs. Taylor, Thompson and Smulski's book, in which two curves or type-gradings are given, one for a practical mix and one for an "ideal" mix; the latter is stated to be too harsh for general use.

These curves for the $\frac{3}{4}$-inch and $1\frac{1}{2}$-inch maximum stone sizes are shown in full lines in *Figs. 3* and *4*, the lower curve in each case being the "ideal" mix and the upper curve the practical mix, which seems to be the

Fig. 3.



most applicable to general practice. It will be observed that these practical mix curves indicate about 7–8 per cent. more fines in the region of the $\frac{3}{16}$-inch and No. 7 sieves, which contribute to workability. From these curves, the percentages passing the various sizes of sieves can be

ascertained. They are tabulated in Table II, and represent the figures which must be aimed at in designing the mix.

TABLE II.

Sieve size.	No. 100.	No. 52.	No. 25.	No. 14.	No. 7.	$\frac{3}{16}$-inch.	$\frac{3}{8}$-inch.	$\frac{3}{4}$-inch.	1-inch.	$1\frac{1}{2}$-inch.
Percentage passing, $1\frac{1}{2}$-inch maximum size of stone . . .	15	17	21	26	32	38	47	65	77	100
Percentage passing, $\frac{3}{4}$-inch maximum size of screenings . .	16	21	25	31	37	46	64	100	—	—

Assuming that a concrete containing 550 lb. of cement per cubic yard is required, the following procedure applies in designing the mix. For materials in Northern Ireland a weight of concrete of 155 lb. per cubic foot would be a good average figure.

This gives 27×155	$=4,185$	lb. per cubic yard
less 8 per cent. for combined water	334	,, ,,
	3,851	
less 550 lb. per cubic yard for cement	550	,, ,,
∴ Weight of sand and stone	$=3,301$	,, ,,

and ratio cement/aggregate = 550 : 3,301 = 1 : 6 approximately.

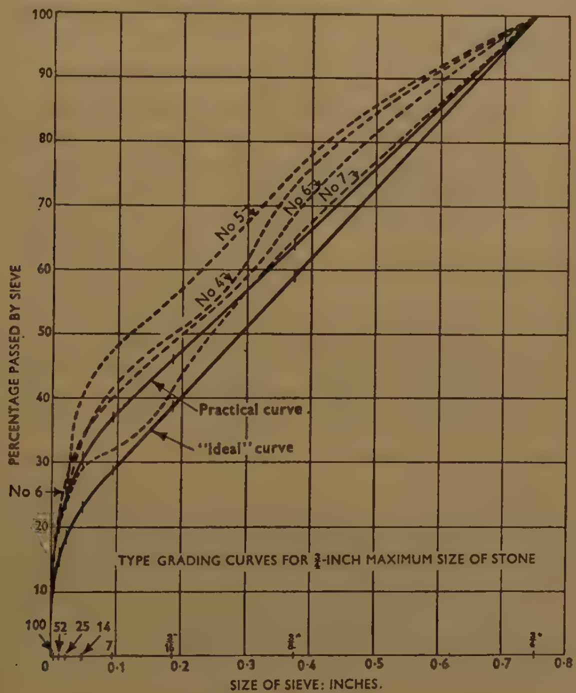
The cement is therefore one-seventh or, say, 14 per cent. of the whole solid constituents. The figure of 14 per cent. for the cement is now adopted in the computation of the trial mix. Such a mix should yield a concrete containing 550 lb. of cement per cubic yard, and this should be checked by direct measurement of a piece of finished concrete. The remaining 86 per cent. must be made up of sand and stone, in the proportions of approximately 1 : 2. For a first approximation in this case, 30 per cent. of sand and 56 per cent. of stone is assumed, that is, cement 14 per cent., sand 30 per cent., stone ($1\frac{1}{2}$–$\frac{3}{8}$-inch) 56 per cent.

These percentages are set out at the top of the cement, sand and stone columns, as shown in Example 3. The grading analyses of the aggregates to be used are then set down in the "Y" columns under their respective headings. As all the cement is finer than the No. 100 sieve, 100 per cent. passes through all the sieves and similarly, in the case of $\frac{3}{8}$-inch stone, if used, 100 per cent. must pass through all sieves larger than $\frac{3}{8}$-inch.

In the adjacent columns "X", 14, 30, 56 per cent. respectively of the analysis-figures given in column "Y" are entered. Finally, these latter figures (in column "X") are added horizontally, and are inserted in the column headed "Mix." Comparing the trial mix with the figures in the column headed "Specified Typegrading" (which are the results obtained from the practical curve), it will be evident that in this particular case,

there is too much material passing the finer sieves, whilst the larger sizes are reasonably close; the sand-content should therefore be reduced, and the stone percentage increased. By varying the percentages of sand and stone, the result given in Example 4 is obtained, and this is the nearest approach which is attainable by the use of these particular materials. If a closer result is required, and the supply cannot be improved, two sizes

Fig. 4.



of stone may be used with the same sand, and this may result in a better mix. This is indicated in Example 5.

Having now arrived at a reasonable mix, all that remains is to convert the 14 per cent., 25 per cent., and 61 per cent. of materials into figures suitable for use behind the mixer for, say, a "one bag" mix; for example,

	Cement.	Sand.	Stone.
	14 per cent.	25 per cent.	61 per cent.
or	112 lb.	200 lb. dry.	490 lb.
or	1 bag.	1·8 cubic foot dry.	4·65 cubic feet.

This method of designing the mix may appear long and involved, but the whole process described has to be carried out only when designing a

new mix, and when adjusting for variations in aggregates supplied the results can be calculated very quickly.

Results obtained in Practice.

The broken-line curves in *Figs. 3* and *4* illustrate some results obtained by the Author in practice, with local aggregates. Curves Nos. 1, 2, and 3 were obtained with one size of stone, and natural sand, whilst curves Nos. 4, 5, 6, and 7 resulted from the use of two sizes of stone and a different sand. The proportions of the various mixes and the test results, where available, are given in Table III.

TABLE III.

Curve No.	Cement: bags.	Sand A or B: cubic feet (dry).	⅜-inch screenings: cubic feet.	¾-inch screenings: cubic feet.	1½–¾-inch stone: cubic feet.	6-inch test-cube.	
						Strength: lb. per square inch.	Weight: lb.
1	1	A 1·84	—	—	5·10	—	—
2	1	A 1·69	—	—	5·30	4,300	20·0
3	1	A 1·72	—	—	5·20	—	—
4	1	B 2·60	1·66	2·50	—	—	—
5	1	B 3·35	1·25	2·80	—	2,300	18·8
6	1	B 2·52	1·25	3·73	—	3,900	19·0
7	1	B 1·25	1·00	3·50	—	—	—

These curves appear to indicate that, using only one size of stone, it is difficult to obtain an approximation to the practical curve, as there is little possibility of adjustment, whereas, when two sizes of stone are used, better agreement may be achieved. As an ultimate, if rather impracticable, solution, except on very large jobs, stones of each size, together with fine and coarse sand, could be stocked and mixed exactly to any desired curve.

Reference to the curves (*Figs. 4*) also shows that the stronger and denser concrete curve (No. 6) lies nearest to the practical curve.

The "ideal" separate grading-curves for sand and stone, mentioned on p. 66, *ante*, originate in the process described above, and represent gradings which, when thus combined, would give a mix exactly on the practical curve. These "ideal" sand and stone gradings are complementary, and are "ideal" for only one particular cement-content, namely, 550 lb. per cubic yard; it is also incorrect to take the "ideal" sand curve complementary to the 1½-inch stone and to use it with ¾-inch screenings, even without a change in cement-content.

Reference to Examples 6 and 7, p. 77, *post*, will show that with a fixed cement-content, the sand required for use with 1½-inch stone is quite different in grading to that used with ¾-inch screenings; and that a change

in cement-content would upset the "ideal" grading-curves. It was from these examples that the individual "ideal" sand and stone grading-curves (*Figs. 1* and *2*) were obtained.

All the foregoing is intended to show that actually no sand and no stone can be "ideal" except in one particular relationship and for one particular cement-content: for that reason it is always better to consider the gradings of a complete aggregate, including cement.

Bulking of Sand, and Water/Cement Ratio.

In all the mixes mentioned so far, the volume of sand has been specified as dry. Unfortunately, sand in that condition is very seldom obtainable in practice, and therefore an allowance will have to be made for the variation in bulk due to the amount of moisture it may contain. The method of making this allowance entails the determination of the percentage by weight of the moisture, by one of the methods described below, and thereafter the percentage increase in bulk is obtained from a bulking curve, examples of which are given in *Fig. 5* for sands A and B.

To make allowance for this increase in bulk of the sand a larger quantity of sand must be put into the mixer; for example, supposing that sand B has a 5-per-cent. moisture-content, the bulking curve for sand B (*Fig. 5*) gives the bulking as 33 per cent., so that in the mix-example worked out previously, where 1·8 cubic foot of dry sand was required, it was necessary to put 33 per cent. more damp sand into the mixer, that is 2·4 cubic feet altogether.

That quantity of moist sand will contain $2{\cdot}4 \times 106 \times \frac{5}{100} = 13$ lb. of water, and this must be allowed for when considering the water/cement ratio. Using a water/cement ratio of 0·6, in a one-bag mix, $112 \times 0{\cdot}6 = 67{\cdot}5$ lb. of water is required; and allowing for the 13 lb. of water borne by the sand, only 54·5 lb. of water, or 5·5 gallons, will be required for the batch. The importance of maintaining the correct water/cement ratio cannot be over-emphasized, as the curves in *Fig. 6* show how quickly the strength falls off above or below the optimum ratio of approximately 0·6.

Methods of Determining the Moisture-Content and Bulking.

One method of determining the moisture-content of the sand is by drying and direct measurement. If 500 grams of the damp sand is dried until no more moisture is given off, and the sample is weighed again, the difference in weight is expressed as a percentage of the dry weight, giving the moisture-content, and the bulking is obtained from the curve (*Fig. 5*). Another method which may be used, and has to be worked out experimentally, depends upon the fact that sand occupies the same volume when inundated as when dry. Here a definite quantity, say, 200 grams of the damp sand, is put into a watertight cylindrical container fitted with a lid, the container is filled with water, and the whole is weighed. From the

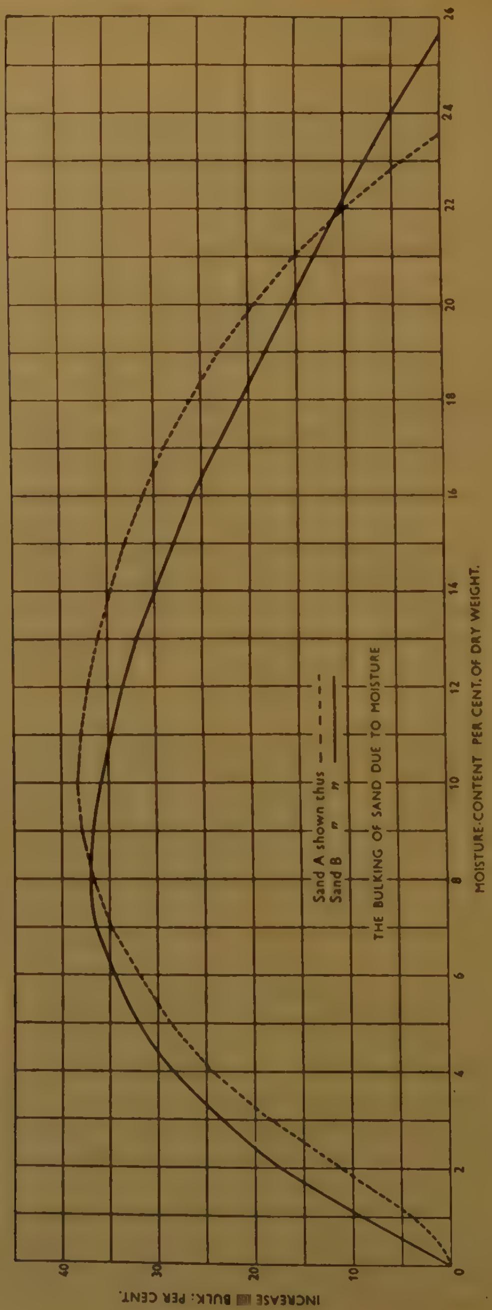
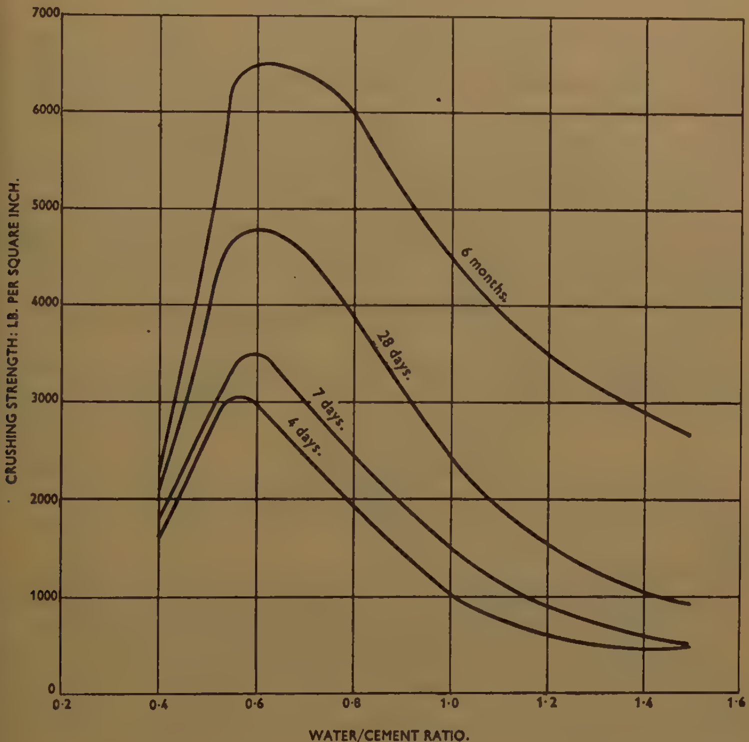

THE BULKING OF SAND DUE TO MOISTURE
Sand A shown thus
Sand B ,,
MOISTURE-CONTENT PER CENT. OF DRY WEIGHT.
INCREASE BULK: PER CENT.
0
2
4
6
8
10
12
14
16
18
20
22
24
26
10
20
30
40

Fig. 5.

resulting weight the moisture-content is obtained directly from a curve, which is plotted by making a series of experimental determinations.

Various patented types of apparatus, mostly based upon inundation methods, are on the market, which enable a direct measurement of bulking and moisture-content to be obtained. If the bulking only is given, the

Fig. 6.



percentage of moisture must then be obtained from the bulking curves, so as to keep the water/cement ratio correct.

The bulking curves (*Fig. 5*) were obtained on the works by the following method: a constant volume of damp sand was measured in a watertight container and weighed; the sample was then dried and weighed again, the difference giving the percentage of moisture; the dry sand was then poured into a measure and the decrease in volume was recorded. The results of a large number of tests with sand containing various percentages of moisture gave the bulking curves shown.

In the Appendix are tabulated the various properties of certain aggregates found in Northern Ireland, upon which the information given in this Paper is largely based.

In conclusion the Author desires to express his thanks to his chief, Mr. R. D. Duncan, B.Sc., M. Inst. C.E., for the facilities rendered available and for the help given in the preparation of this Paper.

The Paper is accompanied by four sheets of drawings, from which the Figures in the text have been prepared, and by the following Appendix.

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EXAMPLE 1.

Grading Analysis No. 56.

Supplier :
Source :
Description : Sand A.

Sieve.	Grams passed.	Percentage passed.	Fineness-modulus.	Remarks.
2-inch . . .	—	—	—	
1½-inch . . .	—	—	—	
1-inch . . .	—	—	—	
¾-inch . . .	2,000	100	0	
⅜-inch . . .	1,952	98	2	
$\frac{3}{16}$-inch . . .	1,805	90	10	
No. 7 . . .	1,624	81	19	
No. 14 . . .	1,100	55	45	
No. 25 . . .	800	40	60	
No. 52 . . .	532	27	73	
No. 100 . . .	192	9	91	

3·0 fineness modulus.

Silt : 3 per cent.
Organic :
Date of delivery : 21/11/39.
Date tested : 21/11/39.

(Tested by) ....

.... 1941.

Example 2.

Grading Analysis No. 57.

Supplier :
Source :
Description : 1½-inch–⅜-inch broken stone.

Sieve.	Grams passed.	Percentage passed.	Fineness-modulus.	Remarks.
2-inch . . .	—	—	—	
1½-inch . . .	4,000	100	0	
1-inch . . .	2,120	53	47	
¾-inch . . .	1,280	32	68	
⅜-inch . . .	5	—	95	
$\frac{3}{16}$-inch . . .	2	—	98	
No. 7 . . .	—	—	100	
No. 14 . . .	—	—	100	
No. 25 . . .	—	—	100	
No. 52 . . .	—	—	100	
No. 100 . . .	—	—	100	

8·08 fineness modulus.

Silt :
Organic :
Date of delivery : 7/11/39.
Date tested : 14/11/39.

(Tested by) ....

.... 1941.

Example 3.

Mix Sheet No. .

Analysis.			No. 56.		No. 57.		No.			
Percent-age.	14		30		56					
Sieve passed.	Cement.		Sand A.		1½–⅜-inch stone.		Stone.		Mix.	Specified type-grading.
	X	Y	X	Y	X	Y	X	Y	X	Y
-inch .	—	—	—	—	—	—	—	—	—	—
½-inch.	14	100	30	100	56	100	—	—	100	100
-inch .	14	100	30	100	30	53	—	—	74	77
-inch .	14	100	30	100	18	32	—	—	62	65
-inch. .	14	100	29	98	—	—	—	—	43	47
$\frac{3}{16}$-inch	14	100	27	90	—	—	—	—	41	38
o. 7 .	14	100	24	81	—	—	—	—	38	32
o. 14 .	14	100	16	55	—	—	—	—	30	26
o. 25 .	14	100	12	40	—	—	—	—	26	21
o. 52 .	14	100	8	27	—	—	—	—	22	17
o. 100	14	100	3	9	—	—	—	—	17	15

Example 4.

Mix Sheet No. .

Analysis.			No. 56.		No. 57.		No.			
Percentage.	14		25		61					
Sieve passed.	Cement.		Sand A.		1½–¾-inch stone.		Stone.		Mix.	Specified type-grading.
2-inch .	—	—	—	—	—	—	—	—	—	—
1½-inch .	14	100	25	100	61	100	—	—	100	100
1-inch .	14	100	25	100	32	53	—	—	71	77
¾-inch .	14	100	25	100	19	32	—	—	58	65
⅜-inch .	14	100	25	98	—	—	—	—	39	47
$\frac{3}{16}$-inch.	14	100	22	90	—	—	—	—	36	38
No. 7 .	14	100	20	81	—	—	—	—	34	32
No. 14 .	14	100	14	55	—	—	—	—	28	26
No. 25 .	14	100	10	40	—	—	—	—	24	21
No. 52 .	14	100	7	27	—	—	—	—	21	17
No. 100	14	100	2	9	—	—	—	—	16	15
	112 lb.		200 lb.		490 lb.					
	1 bag.		1·8 cubic foot dry.		4·65 cubic feet.					

Example 5.

Mix Sheet No. .

Analysis.			No. 56		No. 58		No. 57			
Percentage.	14		25		10		51			
Sieve passed.	Cement.		Sand A.		¾-inch screenings.		1½–¾-inch stone.		Mix.	Specified type-grading.
2-inch .	—	—	—	—	—	—	—	—	—	—
1½-inch	14	100	25	100	10	100	51	100	100	100
1-inch .	14	100	25	100	10	100	27	53	76	77
¾-inch .	14	100	25	100	10	100	16	32	65	65
⅜-inch .	14	100	25	98	5	52	—	—	44	47
$\frac{3}{16}$-inch	14	100	22	90	1	12	—	—	37	38
No. 7 .	14	100	20	81	—	—	—	—	34	32
No. 14 .	14	100	14	55	—	—	—	—	28	26
No. 25 .	14	100	10	40	—	—	—	—	24	21
No. 52 .	14	100	7	27	—	—	—	—	21	17
No. 100	14	100	2	9	—	—	—	—	16	15

EXAMPLE 6.

Mix Sheet No. .

Analysis.			No.		No.		No.			
Percentage.	14		32		18		36			
Sieve passed.	Cement.		Sand.		⅜-inch screenings.		¾-inch stone.		Mix.	Specified type-grading.
2-inch .	—	—	—	—	—	—	—	—	—	—
1½-inch.	—	—	—	—	—	—	—	—	—	—
1-inch .	—	—	—	—	—	—	—	—	—	—
¾-inch .	14	100	32	100	18	100	36	100	100	100
⅜-inch .	14	100	32	100	18	100	—	—	64	64
$\frac{3}{16}$-inch.	14	100	32	100	—	—	—	—	46	46
No. 7 .	14	100	23	71	—	—	—	—	37	37
No. 14 .	14	100	17	53	—	—	—	—	31	31
No. 25 .	14	100	11	34	—	—	—	—	25	25
No. 52 .	14	100	7	22	—	—	—	—	21	21
No. 100	14	100	2	6	—	—	—	—	16	16

EXAMPLE 7.

Mix Sheet No. .

Analysis.			No.		No.		No.			
Percentage.	14		33		53					
Sieve passed.	Cement.		Sand.		1½–⅜-inch stone.		Stone.		Mix.	Specified type-grading.
2-inch .	—	—	—	—	—	—	—	—	—	—
1½-inch.	14	100	33	100	53	100	—	—	100	100
1-inch .	14	100	33	100	30	57	—	—	77	77
¾-inch .	14	100	33	100	18	34	—	—	65	65
⅜-inch .	14	100	33	100	—	—	—	—	47	47
$\frac{3}{16}$-inch.	14	100	24	72	—	—	—	—	38	38
No. 7 .	14	100	18	55	—	—	—	—	32	32
No. 14 .	14	100	12	36	—	—	—	—	26	26
No. 25 .	14	100	7	21	—	—	—	—	21	21
No. 52 .	14	100	3	9	—	—	—	—	17	17
No. 100	14	100	1	3	—	—	—	—	15	15

APPENDIX.

	Sand A.	Sand B.	⅜-inch screenings.	¾-inch screenings.	1½–¾-inch Broken stone.	Remarks.
Weight : lb per cubic foot	112	106	90	95	105	
Specific gravity . . .	2·56	2·57	2·9	2·9	2·9	
Voids : per cent. . . .	29	34	50	47	42	Calculated from specific gravity and volume weights.
Fineness-modulus . .	2·76	3·02	5·16	6·73	7·71	Average.
Typical gradings : sieve passed						
1½-inch	—	—	—	—	100	
1-inch	—	—	—	—	80	Percentages.
¾-inch	100	100	—	100	44	
⅜-inch	97	99	100	26	6	
$\frac{3}{16}$-inch	88	92	63	1	—	
No. 7.	78	82	7	—	—	
No. 14	71	65	4	—	—	
No. 25	58	39	4	—	—	
No. 52	27	17	3	—	—	
No. 100	5	4	3	—	—	

Paper No. 5268.

"Repeated Load Tests on a Voussoir Arch."

By Professor ALFRED JOHN SUTTON PIPPARD, M.B.E., D.Sc., M. Inst. C.E., and LETITIA CHITTY, M.A.

(*Ordered by the Council to be published with written discussion.*) [1]

INTRODUCTION.

THE behaviour of a voussoir arch under concentrated live load and a distribution of dead loads to represent a horizontal filling has already been described[2]. The experimental work has now been extended to determine the effect of repeatedly applying and removing the live load.

It was shown in the earlier Paper that under static load the voussoir arch is considerably stronger than is generally assumed: under actual conditions, however, the live load upon the structure will be applied, not once, but many times. Two series of tests were therefore carried out to determine the effect of repeated application and removal of the load.

EXPERIMENTAL ARCH.

The same arch was used as in the earlier work. The span was 10 feet and the rise 2 feet 6 inches. A detailed description has already been given[3] of the general arrangement as shown in *Figs. 1.* The voussoirs were made of granite concrete blocks measuring 10 inches by 6 inches by 5·8 inches at mid-section. In the first series of tests a rapid-hardening portland cement-mortar was used in all the joints. In the second series, a non-hydraulic lime mortar was used in the joint which was expected to crack, the other joints being as before. As this lime mortar was inadvertently mixed in proportions slightly different from those used in the static tests with lime mortar joints described in the earlier Paper, a strict comparison of the results is not altogether legitimate.

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[1] Correspondence on this Paper can be accepted until the 15th March 1942, and will be published in the Institution Journal for October 1942.—SEC. INST. C.E.

[2] A. J. S. Pippard and R. J. Ashby, "An Experimental Study of the Voussoir Arch." Journal Inst. C.E., vol. 10 (1938–39), p. 383 (January 1939); correspondence in vol. 12 (1938–39), p. 371 (October 1939).

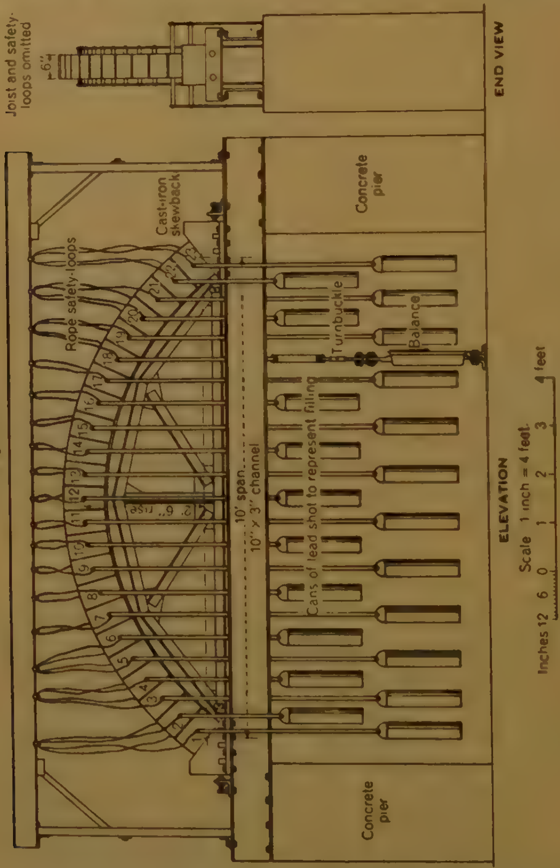
[3] *Ibid.*, p. 386.

Mechanical Arrangement of Test.

The system of dead loads was applied, as before, by means of cans filled with lead shot attached to the various voussoirs.

A diagrammatic sketch of the arrangement for applying the live load is shown in *Fig. 2.* The rocking lever was pivoted to a bracket bolted to two channels which were fastened to the main floor-beams of the laboratory.

Figs. 1.

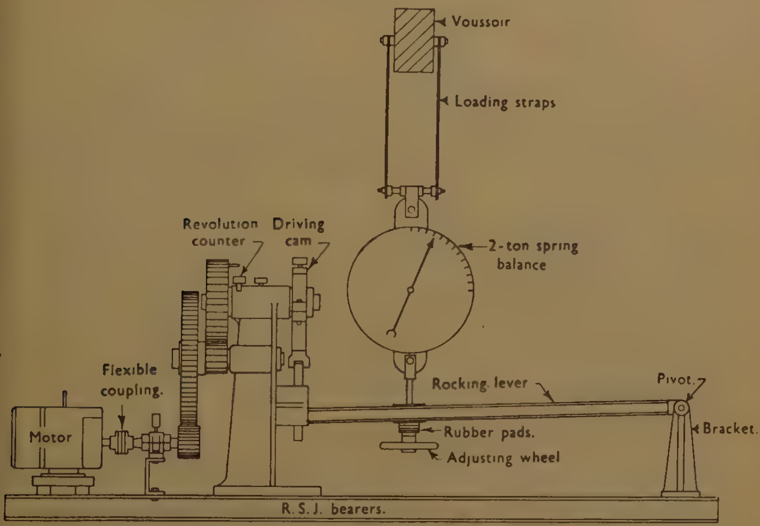


General Arrangement of Experimental Arch.

These channels were at right angles to the centre plane of the arch. The other end of the rocking lever was attached to a slider link, which was connected to a cam driven through a gearing from a ¼-horse-power electric motor. The spring-balance used in the earlier tests was attached to the voussoir, as before, but at its lower end it was provided with a link which passed between the two channels of the rocking lever, being guided by a plate fastened to these channels. The lower end of this link was screwed for a considerable length, and a stop which rested on a hand-wheel was

attached, so that the effective length of the link could be altered by adjusting the position of the wheel. When the rocking lever made contact with this stop a load was applied through the spring balance to the voussoir. By altering the position of the stop on the link the maximum magnitude of the load could be controlled. The stop consisted of a few pads of india-rubber loosely sliding on the link, and formed a shock-absorber. The adjustment of the stop position was made by placing the rocking lever in its lowest position and then screwing up the hand-wheel until the spring-balance recorded the load it was desired to apply to the arch. For every revolution of the cam this load was then applied and

Fig. 2.



ARRANGEMENT FOR APPLYING LOAD.

taken off: the cam was driven at the rate of approximately 65 revolutions per minute.

A revolution-counter was connected to the cam driving-shaft to furnish a record of the number of reversals. As it was impracticable to watch the progress of the experiment continuously, a cut-out device was necessary to ensure that when the joint under test cracked, the motor would stop and the revolution-counter would give a correct reading of the number of repetitions which had caused failure.

ELECTRICAL CUT-OUT DEVICE.

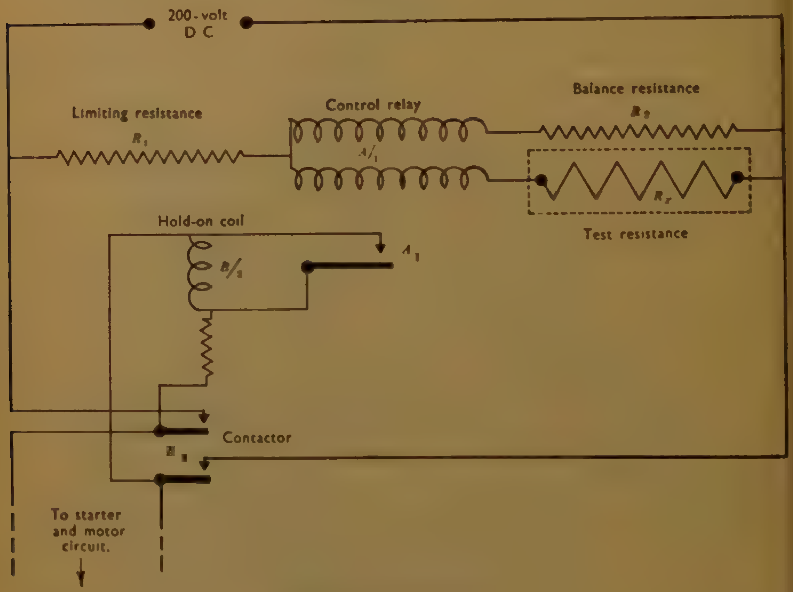
The Authors are indebted to Mr. C. R. Urwin, one of their colleagues in the Electrical Engineering Department of the City and Guilds College, for the design of the cut-out device, which was designed to detect a crack

as small as $\frac{1}{1000}$ inch in width and $\frac{1}{2}$ inch in length. It was fed in parallel with the main motor-circuit from a 200-volt direct-current supply.

The control circuit, shown diagrammatically in *Fig. 3*, consisted of a wire-wound limiting resistance R_1, a double-wound Post Office telephone relay $A/1$, a wire-wound balancing resistance R_2, and the test-circuit R_x.

One end of the limiting resistance R_1 was connected to one terminal of the supply, and the other to the commoned end of the windings of the relay $A/1$. The windings of this relay were identical, and were arranged so that equal values of current in the same direction through the windings

Fig. 3.



CUT-OUT CONTROL.

produced opposing magnetic action; thus so long as the currents remained balanced the relay remained inoperative. The balance of the currents in the windings depended upon the equality of the resistances R_2 and R_x.

If, for any reason, the resistance R_x increased in value, the magnetic action of the windings was thrown out of balance, resulting in attraction of the relay armature. The operation of the armature closed the contacts A_1, which short-circuited the contactor hold-on coil $B/2$ and released the contactor B_2, thereby cutting off the motor-supply and also the supply to the relay-control circuit, thus preventing re-starting of the motor should the resistance R_x regain its original value.

From previous tests it was known that the first crack should appear on the underside of the joint nearest the load, between the load and the

centre of the arch. The resistance R_x was therefore constructed as follows: the underside of this joint was coated with a thin layer of plaster of Paris, and at each extremity a thin brass-foil contact was embedded in the plaster with the surface of the foil exposed. Before the plaster had completely dried a continuous zig-zag pattern of "aquadag" colloidal-graphite paint of line-width $\frac{5}{16}$ inch was painted on its surface, extending the full width and length of the joint and terminating on the brass-foil contacts.

After sufficient time had elapsed for the paint to dry, it was found that deflexional movements of the arch due to loading did not disturb the value of R_x, but that a crack $\frac{1}{1000}$ inch in width in the plaster produced interruption of the circuit R_x by fracture of the paint. The contactor circuit was tripped in about 20 milli-seconds, and so no appreciable movement of the motor occurred after fracture.

The balance relay circuit was used in preference to a direct relay circuit, because in the latter a high value of inductive voltage would be produced at the fracture and, this being only $\frac{1}{1000}$ inch in width, sparking might electrically bridge the circuit, and the operation of the relay would be uncertain.

At the start of each test the resistance R_2 was adjusted to be equal to R_x, and R_1 was adjusted so that the total relay current was about 20 milliamperes. The contactor was then mechanically closed by an external push-rod, and if the control currents through the relay *A/1* were correctly balanced, the contactor was held in by the coil *B/2*. The motor drive was then started and the test proceeded.

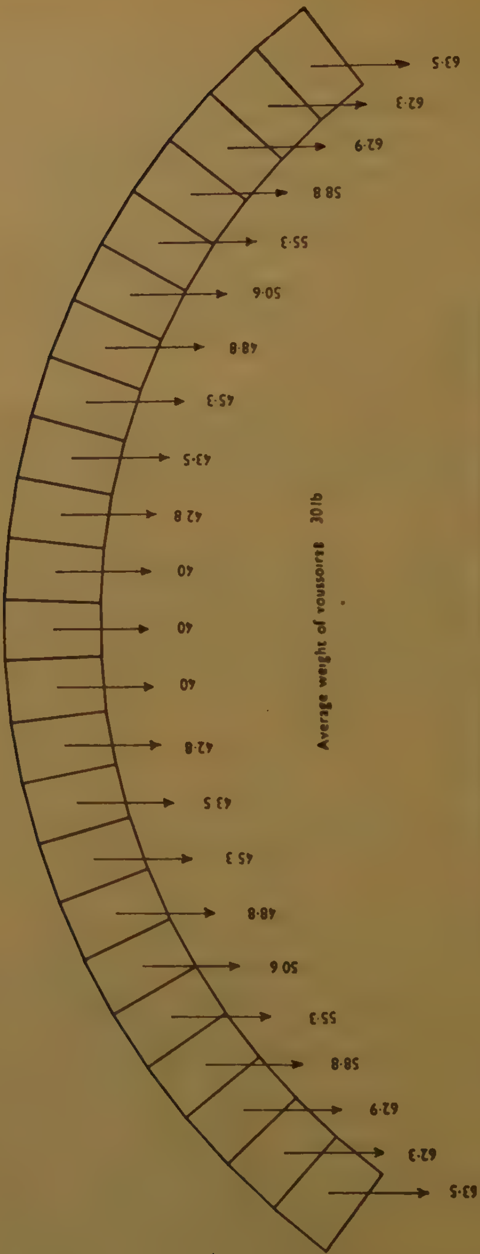
Tests.

The first series of tests was made on an arch of granite-concrete voussoirs with cement-mortar joints. Particulars of the tests are given in Table I.

Table I.—First Series of Repeated Load Tests.

Test.	Period: days.	Voussoir loaded.	Repeated load: lb.	Number of repetitions.	Driving speed: revolutions per minute.
1	21	18	430	over 10^6	30–40
2	13	,,	530	,,	41–65
3	11	,,	670	,,	65
4	11	,,	700	,,	,,
5	11	,,	720	,,	,,
6	11	,,	750	,,	,,
7	11	,,	830	,,	,,
8	11	,,	880	,,	,,
9	11	,,	970	,,	,,
10	—	,,	1,050	8,380	,,

Fig. 4.



LIGHT LOADING SYSTEM (LB.,) INCLUDING WEIGHT OF VOUSSOIRS.

The system of dead loads was that referred to as "light dead loading" in the earlier Paper[1]: the loads on the various voussoirs are shown diagrammatically in *Fig. 4*.

Since the load at which the first crack appeared in the static tests was lowest when the live load was applied to voussoir No. 18 (that is, at about the quarter-point in the span of the arch) the alternating load was applied to this voussoir and the test-resistance circuit was arranged to detect a crack on the intrados of joint 17–18.

After the first test the plaster was removed and the plaster and paint were renewed; but it was not found necessary to renew them again during the series.

Some difficulty was experienced in adjusting the resistances at the beginning of tests Nos. 9 and 10. In test No. 10, after 8,380 reversals, the relay operated. There was no visible sign of crack, and a readjustment of the resistances enabled the contactor to be held in for another 6,750 reversals, when the relay operated again and a crack in the paint, accompanied by sparking, became visible. The engine was then run without the relay circuit, in order to study the development of the crack, which, after some hours, definitely spread into the cement-mortar joint.

The alternating load at which the first crack appeared was 1,050 lb.; the corresponding static load was 1,525 lb.

Particulars of the second series of tests are given in Table II. The

TABLE II.—SECOND SERIES OF REPEATED LOAD TESTS.

Test.	Period: days.	Voussoir loaded.	Repeated load: lb.	Number of repetitions.	Driving speed: revolutions per minute.
1	12	18	330	over 10^6	65
2	11	,,	400	,,	64
3	11	,,	480	,,	,,
4	11	,,	540	,,	,,
5	1	,,	580	over 10^5	,,
6	1	,,	630	,,	,,
7	1	,,	670	,,	,,
8	1	,,	720	,,	,,
9	2	,,	830	,,	,,
10	2	,,	900	,,	,,
11	2	,,	980	171,089	,,

same arch was used: granite-concrete voussoirs with cement-mortar joints, except for joint 17–18, which was of lime mortar. As already stated, this lime mortar was mixed in proportions slightly different from those used in the earlier static tests with lime-mortar joints, and direct comparison is therefore not permissible.

[1] *Loc. cit.*, p. 388.

As the joint proved stronger than was anticipated, the later tests were shortened by making 100,000 instead of 1 million reversals at each load. During test No. 10 two cracks developed, one at the intrados of joint 14–15 and the other at the left abutment 0–1. The load was increased to 980 lb. for test No. 11 and the engine was left to run. After 171,089 reversals the relay operated and a definite crack developed at joint 17–18.

The relay circuit was then cut out, and the load was increased by increments of roughly 100 lb. The engine was run for a few minutes at each load. At about 1,030 lb. a definite crack appeared at the extrados of abutment 23–0. At 1,430 lb. a crack appeared at 7–8 (extrados), and at 1,850 lb. the arch failed in the usual manner by the formation of four pins. The joints opened at

$$0\text{–}1\ i;\ \ 7\text{–}8\ e;\ \ 17\text{–}18\ i;\ \ 23\text{–}0\ e.$$

It is interesting to note that this failing load is practically equal to the load (1,825 lb.), at which failure occurred in the static test for an arch made with limestone-concrete voussoirs and cement-mortar joints[1].

Conclusions.

Unfortunately, the outbreak of war prevented this research from being carried farther. It had been intended to extend the series of tests in the hope that reasonably definite conclusions would be reached in regard to the reduction in load-carrying capacity likely to occur in a voussoir arch owing to the continual passage of traffic.

It is felt, however, that the foregoing description of the apparatus and the results obtained from two lengthy tests are worth recording now. These results indicate that, whilst the first crack in a joint appears at a definitely lower load than in the static tests, the strength of this type of structure is still much greater than is usually assumed in traditional methods of design. The thrust-line, even with lime-mortar joints, was well outside the central middle-third of the ring-depth when tension failure first occurred, and was, in fact, outside the middle three-quarters; but until further tests are possible it may not be advisable to extend the "core" quite to that extent.

The Paper is accompanied by three sheets of drawings, from which the Figures in the text have been prepared.

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[1] *Loc. cit.*, Table IV, test 10, p. 392.

Paper No. 5282.

"The Calculation of the Bearing Capacity of Footings on Clay."

By Guthlac Wilson, S.M., B.Sc. (Eng.), M. Inst. C.E.

(*Ordered by the Council to be published with written discussion.*)[1]

Introduction.

Two considerations enter into the determination of the load-bearing capacity of a clay stratum, namely, safety against failure by settlement and safety against failure by shear. The probable settlement can be estimated by applying Terzaghi's theory of consolidation to the results of tests on undisturbed samples. The factor of safety against failure by shear may be gauged by Prandtl's solution for a surface load, by Terzaghi's approximate method, or by graphical methods: in treating this problem clay, for all practical purposes, may be considered to be a purely cohesive material. Any error resulting from this assumption will be found to lie on the side of safety.

All of these methods are derived from the consideration of strip or wall footings, but they may be used as a guide in estimating the bearing capacity of individual footings, which has been shown to be slightly greater. Prandtl's solution [2] for a surface load is obtained by the analytical determination of the surface of failure in a purely plastic material. Terzaghi's method [3] gives extremely conservative values for the bearing capacity, and is chiefly valuable as it affords a readily grasped picture of how the bearing capacity increases with depth. The graphical methods are all based upon assumptions as to the form of the surface of failure.

The most widely known graphical method is that due to Krey [4], which assumes that the surface of failure consists of a cylindrical surface passing through one edge of the bearing area and a tangent plane making an angle of $45 - \phi/2$ degrees with the horizontal, as illustrated in *Figs. 1*. The

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[1] Correspondence on this Paper can be accepted until the 15th March, 1942, and will be published in the Institution Journal for October 1942.—Sec. Inst. C.E.

[2] Prandtl, L., "*Härte plastischer Körper.*" *Nachrichten Ges. der Wissenschaften zu Göttingen.* 1920.

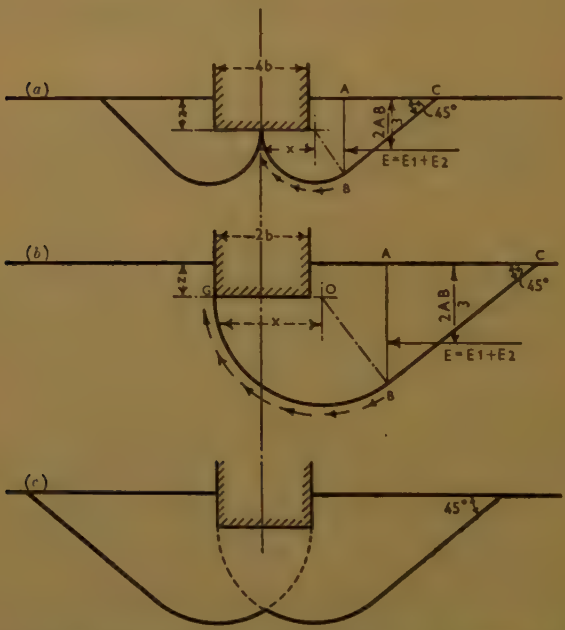
[3] Hogentogler, C. A., and Terzaghi, K., "Inter-relationship of Load, Road, and Subgrade." *Public Roads*, vol. 10, No. 3, p. 37. 1929.

[4] Krey, *Erddruck, Erdwiderstand und Tragfähigkeit des Baugrundes.* Berlin, 1932.

surface which affords the minimum resistance to rupture is determined by a process of trial and error. In the case of a purely cohesive material, ϕ, the angle of internal friction, is zero.

This Paper describes the "circular-arc method"—a simplification of Krey's method, due to Dr. Arthur Casagrande, based upon the assumption that the surface of failure is cylindrical. The position of the centre of the cylindrical surface of minimum resistance is determined analytically, instead of by trial and error. The results obtained are compared with

Figs. 1.



Possible Surfaces of Failure: Krey (Purely Cohesive Material).

those obtained by the entirely different method due to Professor Karl von Terzaghi, M. Inst. C.E., and good agreement is found with regard to the rate of increase of bearing capacity with depth.

Krey's method, and a frequently-used modification thereof, are also considered: the position of the centre of the cylindrical part of the surface of failure is determined analytically, and it is shown that these methods, although applicable to surface loading, are unsatisfactory if applied to the case of a foundation below the surface.

NOMENCLATURE.

$Q_c = 2bq_c$ denotes total load applied, less the weight of earth displaced by the foundation;

$2b$ „ width of foundation;

γ „ unit weight of soil;

x „ horizontal distance of centre of cylinder of failure from the far corner of the foundation (see *Figs. 1, 2,* and *7*).

y „ height of centre of cylinder of failure above level of base of foundation;

z „ depth of base of foundation below the surface;

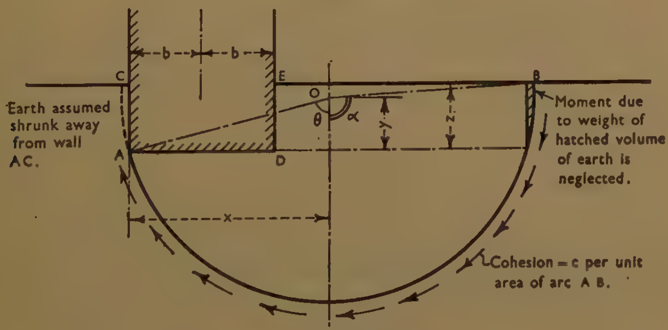
R „ radius of surface of rupture $= \sqrt{x^2 + y^2}$;

c „ cohesion of soil per unit of area.

CIRCULAR-ARC METHOD.

Referring to *Fig. 2*, it is assumed that the earth has shrunk away from the walls, or at least from one wall, to the full depth, and the additional

Fig. 2.



CIRCULAR ARC METHOD.

resistance due to the moment of the weight of the unbalanced segment of the cylinder, shown hatched, is neglected.

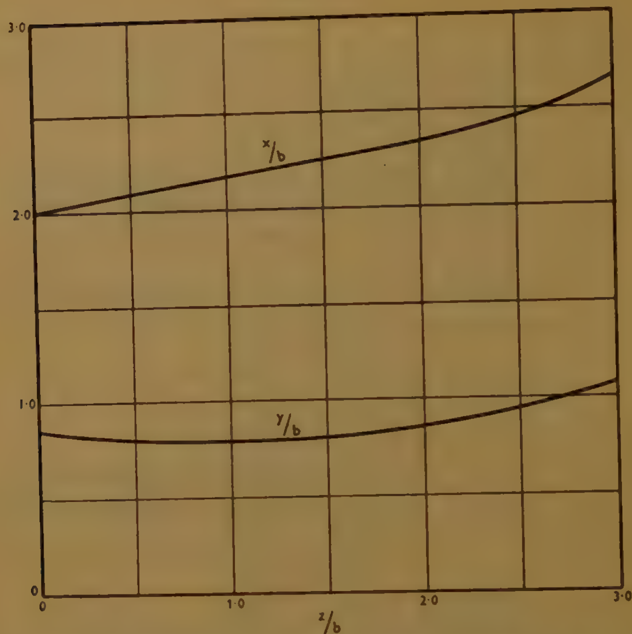
Considering a slice of unit thickness perpendicular to the paper, and taking moments about 0, the centre of the cylindrical surface of rupture,

$$Q_c(x-b) = 2bq_c(x-b) = cR(\theta + \alpha)\, R = cR^2\left[\tan^{-1}\frac{x}{y} + \cos^{-1}\frac{y-z}{\sqrt{x^2+y^2}}\right].$$

Putting $R^2 = x^2 + y^2$,

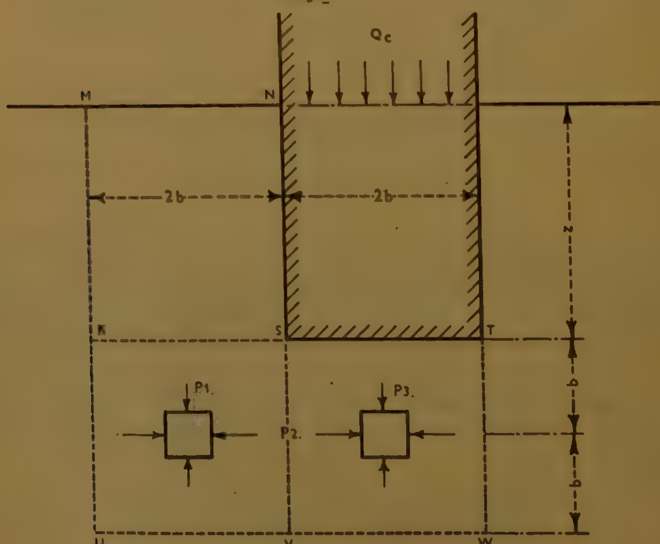
$$Q_c = c\frac{x^2+y^2}{x-b}\left[\tan^{-1}\frac{x}{y} + \cos^{-1}\frac{y-z}{\sqrt{x^2+y^2}}\right] \quad . \quad . \quad . \quad . \quad (1)$$

Fig. 3.



Co-ordinate of Centre of Circle, Various Depths of Foundation.

Fig. 4.



The partial differential coefficients of Q_c with respect to x and y are :

$$\frac{\partial Q_c}{\partial x} = c\left\{\tan^{-1}\frac{x}{y} + \cos^{-1}\frac{y-z}{\sqrt{x^2+y^2}}\right\}\frac{x^2-2bx-y^2}{(x-b)^2} + \frac{c}{x-b}\left\{y + \frac{x(y-z)}{\sqrt{x^2+2yz-z^2}}\right\};$$

and

$$\frac{\partial Q_c}{\partial y} = \frac{2yc}{x-b}\left\{\tan^{-1}\frac{x}{y} + \cos^{-1}\frac{y-z}{\sqrt{x^2+y^2}}\right\} - \frac{c}{x-b}\left\{x + \frac{x^2+yz}{\sqrt{x^2+2yz-z^2}}\right\}.$$

To find the minimum value of Q_c, put $\frac{\partial Q_c}{\partial x} = 0 = \frac{\partial Q_c}{\partial y}$, whence

$$\tan^{-1}\frac{x}{y} + \cos^{-1}\frac{y-z}{\sqrt{x^2+y^2}} = \frac{b-x}{x^2-2bx-y^2}\left\{y + \frac{x(y-z)}{\sqrt{x^2+2yz-z^2}}\right\} \quad . \quad . \quad (2)$$

$$\tan^{-1}\frac{x}{y} + \cos^{-1}\frac{y-z}{\sqrt{x^2+y^2}} = \frac{1}{2y}\left\{x + \frac{x^2+yz}{\sqrt{x^2+2yz-z^2}}\right\} \quad . \quad . \quad . \quad . \quad (3)$$

Substituting $x = my$ and $z = ny$ in equation (3),

$$\tan^{-1}m + \cos^{-1}\frac{1-n}{\sqrt{m^2+1}} = \frac{1}{2}\left\{m + \frac{m^2+n}{\sqrt{m^2+2n-n^2}}\right\} \quad . \quad . \quad . \quad (4)$$

If various values be selected for n, equation (4) can be solved for m. Then x and y can be found by equation (2), and $q_c = \frac{Q_c}{2b}$ can be found from equation (1) by use of the value found for the sum of the angles θ and α when solving equation (4).

Fig. 3 gives the co-ordinates of the centre of the circle for various ratios of depth of footing to half-breadth, and *Fig. 6* gives the bearing capacity at various depths. If $z = 0$, q_c/c is found to be $5{\cdot}52c$, which agrees with the result previously found by Fellenius[1].

Comparison with Results Obtained by Terzaghi's Method.

It is useful to compare the results with those obtained by Terzaghi's method. This method is approximate and is known to give results on the low side, but until now it has been the only analytical method indicating how the bearing capacity increases with the depth.

The derivation of Terzaghi's method is as follows : considering *Fig. 4*,

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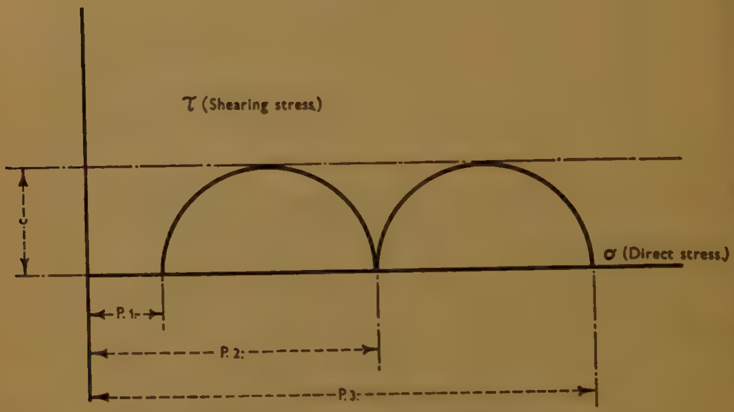
[1] Fellenius, W., *Teknisk Tidskrift*, 1929, p. 27 ; 25 May, 1929 ; and reprinted in *Erdstatische Berechnungen*. Berlin, 1940.

the cube RSVU restrains the cube STWV, under the foundation, from expanding laterally; the cube RSVU, in turn, is prevented from heaving up by three factors, namely, the weight of earth above; the shear on the surface RM; and the friction on the wall face SN.

Now in a purely cohesive material the maximum difference between

Fig. 5.



MOHR'S CIRCLES: TERZAGHI'S METHOD.

the two principal stresses anywhere is constant and equal to $2c$ (*Fig. 5*). Hence:

$$p_1 = (z + b)\gamma + \frac{zc}{2b} + \frac{z\alpha c}{2b}$$

where α is a coefficient ranging from zero in the case where the soil has shrunk away from the wall, to a maximum of unity:

then $$p_2 = p_1 + 2c; \; p_3 = p_2 + 2c = p_1 + 4c;$$

and $$q_e = p_3 - (b + z)\gamma + \frac{2\alpha cz}{2b};$$

the last term being the friction on the two sides of the wall. Substituting for p_3,

$$q_e/c = 4 + \frac{(1 + 3\alpha)}{2} \cdot \frac{z}{b}.$$

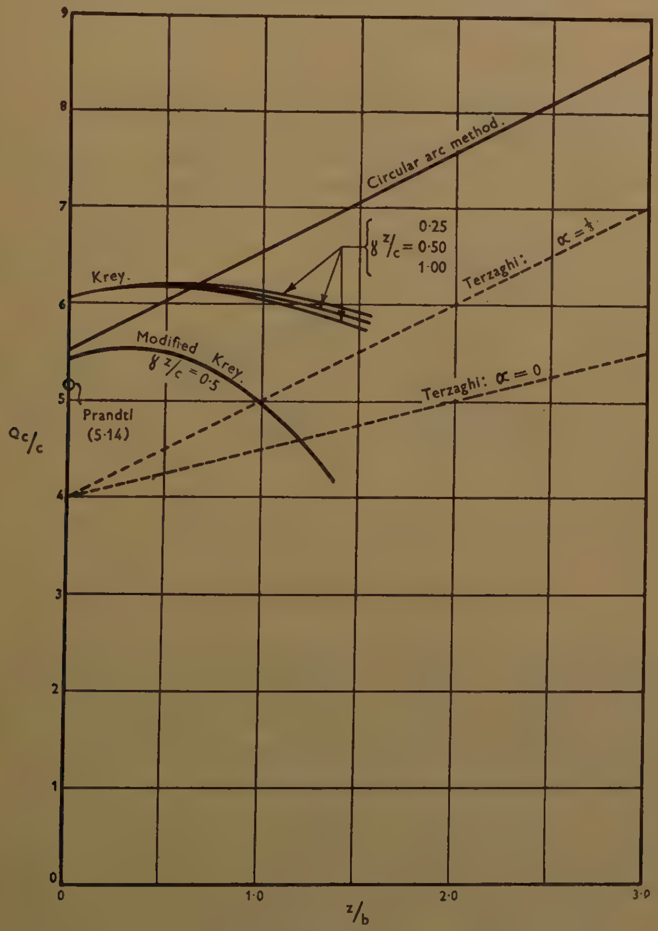
The bearing capacities calculated from this formula when $\alpha = 0$ or $\frac{1}{2}$ have also been plotted on *Fig. 6*. It will be noted that the increase of bearing capacity with depth calculated by the circular-arc method is practically the same as that calculated by Terzaghi's method, when $\alpha =$

Krey's Method.

Krey[1] assumes that the axis of the cylinder of failure lies in the plane of the base.

Referring to *Figs. 1* (*b*), the moment of the load and earth prism ABG about O is resisted by the moments of the cohesion on the arc BG and the

Fig. 6.



Ultimate Bearing Pressures.

orce E acting across the surface AB. The force E may be sub-divided nto E_1, the force necessary to shear the clay on the surface BC, and E_2,

[1] *Loc. cit.*

the force necessary to raise the earth prism ABC along the slope BC. Both E_1 and E_2 are assumed to act at two-thirds of the depth AB.

It is easy to show that

$$\frac{q_c}{c} = \frac{1}{12b(x-b)}\left[\frac{x^2}{2}(9\pi + 8) + 2\sqrt{2}xz - z^2\left(4 + \frac{\gamma z}{c}\right)\right].$$

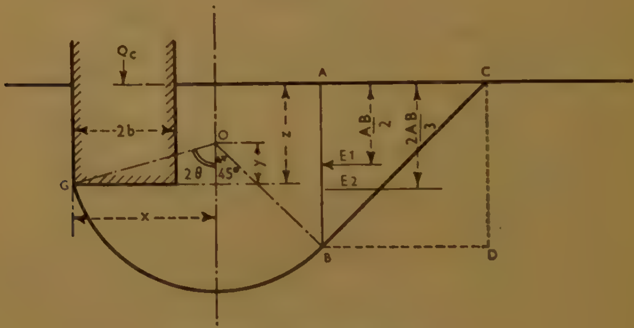
Differentiating with respect to x, and equating to zero,

$$x = b + \sqrt{b^2 - Z},$$

where
$$Z = \frac{1}{9\pi + 8}\left[2z^2\left(4 + \frac{\gamma z}{c}\right) - 4\sqrt{2}bz\right].$$

These equations have been solved and the resulting values of q_c have been plotted in *Fig. 6*. It will be seen that, at the surface, $q_c = 6{\cdot}047c$:

Fig. 7.



Modified Krey Method.

the value of q_c then increases to a maximum of about $6{\cdot}20c$, when $z = \frac{1}{2}b$, and thereafter declines. Such a result is contrary to reason. It has been pointed out that Krey assumes that the axis of the cylinder of rupture lies in the plane of the base. This assumption is avoided in a modification of Krey's method, often adopted in the United States, which also includes another correction. The force E_1 really acts at half the depth AB (*Figs.* and 7), instead of being collinear with the force E_2, which acts at two-thirds of the depth: this can be readily demonstrated by completing the quadrangle ABCD (*Fig.* 7), which may be regarded as one face of a compression test-cube: the force E_1 is the compressive force required to cause failure and, by symmetry, acts at the centre of AB.

It can be shown that

$$q_c = \frac{\gamma z(3yz - z^2) + c\left[(x^2 + y^2)\left(6\tan^{-1}\frac{x}{y} + \frac{3\pi}{2}\right) + 3(x^2 - y^2 - 2z^2 + 4yz)\right.}{12b(x-b)}$$

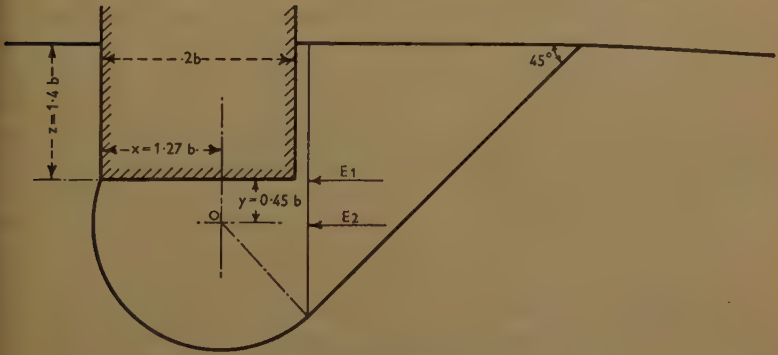
Differentiating with respect to x and y, and equating to zero, the following simultaneous equations for the determination of x and y are obtained:

$$\frac{\gamma z}{c}\left[\frac{3yz}{b^2} - \frac{z^2}{b^2}\right] - 3\left[\left(\frac{x}{b} + \frac{y}{b}\right)\left(\frac{x}{b} + \frac{y}{b} - 2\right) + \frac{2z}{b}\left(\frac{z}{b} - \frac{2y}{b}\right)\right]$$
$$= \left[\frac{x^2}{b^2} - 2\frac{x}{b} - \frac{y^2}{b^2}\right]\left(6\tan^{-1}\frac{x}{y} + \frac{3\pi}{2}\right)$$

and
$$2\left(\frac{x}{y} + 1 - 2\frac{z}{y}\right) - \frac{\gamma z}{c}\cdot\frac{z}{y} = 4\tan^{-1}\frac{x}{y} + \pi.$$

Reference to *Fig. 6* will show that, as might be anticipated, the values for q_c are lower in all cases than those found by the original Krey method.

Fig. 8.



MODIFIED KREY METHOD TO SCALE: $z = 1{\cdot}4b$.

At the surface $q_c = 5{\cdot}41c$, which is closer to the value found by Prandtl; it then rises slightly to a maximum at $z = 0{\cdot}4b$, and declines rapidly as the ratio of z to b is further increased. The reason for this decrease in the value of q_c will be evident on inspection of *Fig. 8*, which has been plotted to scale from the values for x/b and y/b, calculated for the case when $\frac{z}{b} = 1{\cdot}4$. In this case the centre of the cylinder of rupture lies below the line of action of the force E_1, and this force therefore enters the calculation as a force tending to cause failure instead of resisting it. If the force E_1 were considered to act at two-thirds of the depth AB, as taken by Krey, that state of affairs would not be reached until z/b had attained a somewhat greater value, but the inherent fallacy would still be present.

The fallacy lies in the fact that, although the cohesion along the slope BC cannot become an active force tending to overturn the foundation, analytical or graphical search for a minimum brings it into the calculation in this guise when once a certain foundation depth has been exceeded.

Conclusions.

The criteria by which any method for the determination of the bearing capacity of a purely cohesive material should be judged are two: that reasonable agreement with Prandtl's solution should exist for the case of surface loading, and that the bearing capacity should increase with the depth of the footing.

It has been shown that the circular-arc method, which has the advantage of simplicity, satisfies these criteria: the bearing capacity determined for the case of surface loading differs from that obtained by Prandtl by only 7·4 per cent., and the rate of increase of bearing capacity with depth is in good agreement with that obtained by Terzaghi. Krey's method, and the modification thereof, will lead to erroneous results if applied to other cases than that of surface loading.

One further point arises with regard to the circular-arc method. It will be seen by reference to *Fig. 3*, that the centre of the cylinder of rupture lies below the surface of the ground when the value of z/b exceeds 0·8. In that event, it would appear more logical to replace the part of the arc above the horizontal radius by a vertical tangent. The difference in the length of surface to be sheared is small, in fact negligible within the limits of z/b for which results are given in this Paper, but the point would be worthy of consideration in the design of exceptionally deep footings.

Acknowledgement.

This Paper was begun while the Author was studying at Harvard University, and he owes much to the encouragement of Professor Arthur Casagrande; more recently he has benefited from discussions with Mr. A. W. Skempton, M.Sc. (Eng.), Assoc. M. Inst. C.E., and he is also indebted to Messrs. J. E. Levings and P. R. Harmer, Stud. Inst. C.E., for assistance in checking and making the numerical calculations.

The Paper is accompanied by seven sheets of drawings, from which the Figures in the text have been prepared.

Paper No. 5258.

"The Problem of a Bar Harbour at Greymouth, New Zealand."

By David Croll Milne, B.Sc., M. Inst. C.E.

(*Ordered by the Council to be published in Abstract form.*)[1]

The first part of the Paper deals with the construction of extensions to the breakwaters, which were of the rubble mound type. The stone required for this work was obtained from a limestone quarry situated near the harbour, and in order to produce the stone in sufficient quantity it was decided to fire a large tunnel shot on a scale which had not hitherto been attempted in the Dominion. The execution of this project, which presented unusual features, is described in detail:

The total length of tunnel driven was 393 lineal feet, and the average cross section was 3 feet 6 inches by 3 feet 6 inches. The total weight of stone removed from the tunnel was 357 tons, and the total quantity of gelignite used was 575 lb., or 0·621 ton of stone per pound of gelignite. The charge consisted of 14,600 lb. of black powder, which was distributed over eight chambers in quantities which varied between 950 lb. and 2,550 lb., and the shot was fired electrically through a transformer connected to the mains. A survey made after the blast gave the quantity of stone brought down as 105,000 tons or 7·2 tons of stone per pound of powder. The cost per ton, including all charges, amounted to 3·91 pence.

Concurrently with the construction of the breakwaters a careful investigation, extending over a number of years, was conducted into the question of bar conditions with a view to discovering whether the harbour entrance could be improved by an alteration in the alignment or relative positions of the breakwaters, or whether the effect produced on the bar by the breakwater extensions could be supplemented by other works.

An initial step in the inquiry was to establish definitely the cause of the extremely rapid variations both in location and extent which are characteristic of the Grey Bar, and to determine whether these unstable conditions were produced by detritus carried down by the river or whether they were due to external agencies which had their origin in off-shore or coastal conditions.

The material carried down by the river in flood consists chiefly of very

[1] The full MS. and illustrations may be seen in the Institution Library.—Sec. Inst. C.E.

heavy gravel ranging up to 6 inches in diameter, and the current-velocity during floods occasionally exceeds 10 knots. The effect of floods on the bar is generally to improve the depth of water, whilst shoaling occurs at the berthages. Under normal conditions the current-velocity does not exceed 2 knots, and the only material brought down by the river is fine mud and silt which passes out to sea without being deposited on the bar. Samples of material taken from the bar from time to time were found to consist of fine sand, the grains of which had the rounded appearance characteristic of sea sand, whilst the material dredged from the berthages was coarse gravel containing generally not more than 10 per cent. of sand, the grains of which were coarse and angular in appearance. It was apparent, therefore, that the bar was not formed by detritus carried down by the river and that the influence exercised by the latter on the harbour entrance was due to fluctuations in the scouring action produced by variations in current-velocity on material carried along the coast by ocean currents or wave action.

The existence of a main ocean current moving in a northerly direction along the coast appears to be a firmly-established local tradition, but a careful investigation carried out in this connexion did not support this belief. A large number of surface and deep-water floats were used and many observations were taken within a radius of 2 miles seaward of the harbour entrance. The method employed was to use two floats in each series of observations. One float was controlled by vanes set at a depth of 3 feet below the surface, whilst the vanes of the other were set at 12 feet below the surface-level. Both floats were released simultaneously at mid-stream opposite pier No. 245 at the lower end of the wharf, and the current-velocities were measured between this point and the light on the head of the south breakwater. Outside the harbour entrance the paths of the floats were located by means of theodolite bearings, two instruments being used, one on the head of the south breakwater and the other on the head of the north breakwater.

The following is an analysis of the off-shore current observations :—

Direction.	*Percentage.*	*Velocity : feet per minute*
South	33	44–86
West	45	64–155
North	22	106–420

The high velocity of approximately $4\frac{1}{4}$ knots which was recorded in the case of one float in a northerly direction occurred during a period of heavy south-westerly swell when the observed height of the waves at the harbour entrance was 6 feet. In each of the other cases where the floats took a northerly course the swell was from the south-west and the observed height of waves at the harbour entrance ranged between 4 feet and 6 feet. The relatively high velocities attained by the floats which moved in a northerly direction were due to the combined effect of the river current and the heavy

south-westerly swell. The result of these observations was to eliminate ocean currents as agencies in producing shoaling of the bar.

It was established, however, that accretion at the harbour entrance occurred during periods of south-westerly seas, and during these periods material accumulated rapidly on the foreshore to the south of the harbour. The material on the beach consisted chiefly of fine sand comparable with samples obtained from the bar.* The rate of accretion was generally uniform along the foreshore, and on one occasion, after 14 days of continuous south-westerly seas, the level of the beach was raised from 2 to 4 feet between high- and low-water marks. The quantity of material deposited during this period on the beach between the south breakwater and a point 1 mile to the south amounted to approximately 80,000 cubic yards. The period of south-westerly swell was followed by 48 hours of northerly seas, which produced rapid erosion of the foreshore and lowered the beach-level by an average of 3 feet. The erosion was most pronounced near low-water mark, where the level of the beach dropped a maximum height of more than 5 feet. It was estimated that, of the 80,000 cubic yards accumulated during the period of 14 days, approximately 50,000 cubic yards was removed during the 48 hours of northerly seas.

Observations taken over a long period established that south-westerly seas were always accompanied by accretion on the foreshore, whilst northerly seas, which rarely exceed 48 hours' duration, produced exceedingly rapid erosion. The rate of travel of material along the beach was measured and it was established that during moderate northerly seas the sand and shingle moved southwards at an average rate of ½ mile per 24 hours, and that during heavy seas the rate of travel was increased to approximately 1 mile in 24 hours. The rate of travel of sand and shingle along the beach in a northerly direction varied between ¼ mile and ½ mile in 24 hours, according to sea conditions.

The investigation revealed that fluctuations in bar-depth varied with the movement of the littoral drift along the coast from south to north under the influence of the prevailing south-westerly swell. Under normal conditions the river velocity is sufficient to deal effectively with the littoral set, and a state of equilibrium results with the bar-depth more or less stable. If this state of equilibrium is disturbed by an increase in the littoral drift or by a decrease in the river current, temporary and local accretion will result. In the rare event of these factors being coincident, serious shoaling inevitably occurs.

Observations taken on the beach and surveys made of the bar convinced the Author that any scheme which was designed to effect an improvement in bar-depth would have to deal with enormous quantities of material. The littoral drift along the coast amounts to approximately 1¼ million cubic yards per annum, and any system of groynes designed to build up the beach permanently would quickly become buried and inoperative so far as exercising any influence on the bar was concerned But it

had been definitely established that rapid erosion took place during northerly seas, and this led the Author to suppose that it might be possible to arrest the travel of a considerable portion of the littoral drift by a system of groynes constructed on the beach to the south of the harbour entrance, and that the material so accumulated would be eroded during northerly seas, thereby restoring the groynes to a condition which would enable them to operate effectively during the next period of southerly weather. Thus there would be no serious disturbance of the natural conditions which obtain along this coast, whilst the effect of the groynes would be to increase the accretion during south-westerly seas and to arrest the travel of the littoral drift before it reached the harbour entrance, so that an improvement in bar-depth might reasonably be expected.

It was determined by large-scale experiment that groynes constructed in a south-westerly direction at an angle of approximately 50 degrees to high-water mark gave the best results. Twelve timber groynes, each consisting of three sections 50 feet in length, with a gap of 5 feet between each section, were constructed between high- and low-water marks, at a cost of £207 per groyne. The distance between groynes was 400 feet.

The alternation of accretion during south-westerly seas and erosion during northerly seas continued to be unaffected by the construction of the groynes, except that the rate of accretion was greatly accelerated and the volume of material arrested was considerably increased.

The effect of the groynes upon the bar-depth has been considerable. The rapid variations in the navigable depth of the harbour entrance which have in the past restricted the movements of shipping have become less frequent and of smaller amplitude, and the bar-depth has become stabilized within limits which enable ships under normal conditions to enter and leave the port loaded down to their full load draught.

LATE CORRESPONDENCE
ON PAPERS PUBLISHED IN
FEBRUARY 1941 JOURNAL.

Paper No. 5183.

"The Uhl River Hydro-Electric Project." †

By Herbert Percival Thomas, C.I.E., B.Sc.

The Author, in reply, observed that some limit had to be placed upon the length of a Paper and if it were expanded to cover non-technical newspaper articles, speeches, reports of committees, etc., it would be impossible to keep its length within the bounds of reason. He had made no attempt to discuss the political or other reason for the development of the Uhl river site.

The reason further attention had not been given to the mention of the reconnaissance of the Uhl river on p. 159 of the report of the Hydroelectric Survey of India, was that that survey appeared merely to have considered the development of the stream at, or near, its junction with the Beas river in Mandi State, and not the possible development by tunnelling through the Range at the present site, about 38 miles upstream.

It was difficult to agree that the figures of cost were in doubt, since all of them had been taken from the duly audited accounts, prepared by the Accountant-General's department, which included interest during construction, compounded annually, as well as what had always seemed an inordinate charge, made yearly for the maintenance of his accounting staff engaged in any work connected with the project.

In regard to the railway, the costs, as recorded in the Paper, included the annual subsidy paid by the project to the North-Western Railway, in addition to the freight and other transportation charges.

It should be understood, further, that the extension of rail-head from Pathankot to Jogindernagar was not undertaken for the benefit of the Uhl river project, but because the Railway Commissioners considered that the thousands of tons of cement, machinery, and supplies which would have

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† Journal Inst. C.E., vol. 15 (1940–41), p. 280 (Feb. 1941).

to be carried during the construction years, would provide a valuable scource of revenue to the line, whilst the shipping business of the Kangra valley, with its slate quarries, sugar-cane, and cereal crops, and also that of the Uhl valley, famous for its fruit, could be built up.

The natural outlet of Mandi State was through Jogindernagar, and that State had engaged experts to advise on the establishment of an acid factory, whilst the salt from its mines was being sent down in ever-increasing quantities. The seeming attractiveness of the proposed line was further increased by the discovery in Mandi of a high-grade coal outcrop, and the State was also known to have iron ore deposits, as yet undeveloped. All those facts had a distinct bearing on the building of the line. The Uhl river head-works were at an elevation of 6,000 feet, and had never been frozen over.

A careful investigation of the possibility of canal fall development had been made, but it had to be remembered that canals in the Punjab were all silt-bearing, and that on account of other and constructional difficulties they promised to be smaller and more costly than would appear from a surface examination; and they required, for their successful utilization, a basic plant, such as the Uhl river project.

Paper No. 5242.

"An Apparatus for Measuring the Lateral Pressure of Clay Samples under a Vertical Load." †

By Geoffrey Morse Binnie, M.A., Assoc. M. Inst. C.E., and John Alfred Price, B.A., Stud. Inst. C.E.

Mr. A. L. Bell pointed out that in the October 1941 Journal the formula

$$p_1 = wh \tan^2\left(\frac{\pi}{4} - \frac{\alpha}{2}\right) - 2\,k \tan\left(\frac{\pi}{4} - \frac{\alpha}{2}\right),$$

though correctly shown on page 486, was incorrectly printed on page 491, where k had been substituted for $2k$ in the formula for dimension (B).

Further, in *Fig. 10* on page 489, the dimension "B" was shown to be 39 lb. per square inch, whereas in the text on the same page it was stated to be 19 lb. per square inch, this latter being the correct figure.

He had claimed that the formula and the diagram both yielded the same result, and that would be found to be the case if the vertical dimension "B" was measured upwards from the horizontal axis of the diagram, which was the third line from the bottom in *Fig. 10*, and not the bottom line as indicated by the arrow-head.

This error in preparing *Fig. 10* from the original diagram was, perhaps, partly due to the fact that he had—in recognition of the known fact that clay had tensile strength and could sustain a pull—deliberately extended the sloping line downwards beyond the horizontal axis to meet the vertical axis.

The graphical method described by him had never before been published, and he hoped that any readers who might have been discouraged in their first reading of his comments would now be able to satisfy themselves that the mathematical and graphical treatments led to identical results.

† Journal Inst. C.E., vol. 15 (1940–41), p. 297 (Feb. 1941).

CORRIGENDUM

October 1941 Journal. p. 593, line 29. *For* "$rv\dfrac{v^2}{2g\mu}$" *read* "$rv + \dfrac{v^2}{2g\mu}$".

OBITUARY.

WALTER LEAHY MANSERGH was born at Hampstead on the 23rd October, 1871, and died at Woking, Surrey, on the 3rd September, 1941. He was educated privately and at University College School, and after an engineering course at University College, London, served a pupilage of 3 years under his father, the late Mr. James Mansergh, F.R.S., Past-President Inst. C.E., during which he was mainly engaged on Parliamentary surveys in Wales for Birmingham water-supply schemes. In 1894 he was appointed an assistant in his father's office, and accompanied him on visits of inspection of water-supply and drainage works at Toronto, Colombo, and Budapest. In 1899 he became resident engineer on the Caban Coch dam of the Birmingham waterworks, but in 1900 resumed his work as assistant to his father. In 1902 he was taken into partnership in the firm, and took an active part in the preparation of designs and the supervision of construction of numerous large water-supply, sewerage, and sewage-disposal schemes in various parts of Great Britain.

Mr. Mansergh was admitted as a Student of The Institution in 1891, was elected an Associate Member on the 12th January, 1897, and was transferred to the class of Member on the 10th March, 1908. In 1912, in collaboration with the late Mr. E. L. Mansergh, M. Inst. C.E., he presented a Paper on "The Works for the Supply of Water to the City of Birmingham from Mid-Wales"[1], for which he was awarded a Telford Gold Medal.

In 1899 he married Anna, daughter of the late Richard Price-Williams, M. Inst. C.E., who predeceased him, and had two sons.

HUGH HAMILTON NEWELL, O.B.E., was born in Belfast on the 29th April, 1878, and died at Mosman, Sydney, New South Wales, on the 15th March, 1941. He was educated first at Erie, Pennsylvania, and later at the Newtown Superior Public School and the Fort Street Model School, Sydney. In 1894, he entered the Public Works Department, Sydney, as an engineer-cadet, and served as an assistant engineer at various country centres in New South Wales until 1907, when he was placed in charge of the National Works District of Newcastle, N.S.W. He became district engineer at Bathurst in 1912, and at Lismore in 1915, and in 1917 was given charge of a sub-branch of the National and Local Works section of the Public Works Department. In 1924 he was appointed district engineer at Wollongong, and also manager of the Port Kembla shipping and electricity supply and of the harbour works. In addition, during the period 1917–1924 he was, on ninety-two separate occasions, appointed

† Min. Proc. Mech. C.E., vol. cxci (Session 1911–12), p. 3.

a Royal Commissioner for municipal schemes involving governmental approval of loans, in respect of roads, bridges, electricity-supply, and drainage works, and exercised the powers of a Supreme Court judge. In 1925 he was made engineering member of the Main Roads Board, and served as its deputy-president from 1928 until January 1932, when he became president. On the constitution of the Board of Transport Commissioners, Mr. Newell was appointed Commissioner for Highways and Transportation, in March 1932; in December of the same year, on the formation of three separate departments under the State Ministry of Transport, he was nominated as Commissioner for Main Roads, controlling also the Sydney Harbour bridge, and retained that office until his death. In 1936 his services were recognized by his appointment as a Commander of the Order of the British Empire. Apart from his official duties, he was interested in educational matters, and was Chairman of The Scots College Council, Sydney, and a councillor of the St. Columba Grammar School.

Mr. Newell was elected a Member of The Institution on the 8th January, 1929. For many years he served on the New South Wales Advisory Committee of the Council, and from November 1929 acted as Chairman of the Committee. He was also a member of the Institution of Engineers, Australia.

In 1903 he married Ethel, daughter of John Holmes Reid, of Tenterfield, N.S.W., and had one son and three daughters.

CHRISTER PETER SANDBERG was born in Sweden on the 11th August, 1876, and died at Crockham Hill, Kent, on the 26th June, 1941. He was educated in Brussels and at Dulwich College, and received his engineering training at the Crystal Palace School of Engineering and University College, London. In 1893 he became an assistant to his father, the late Mr. C. P. Sandberg, M. Inst. C.E., was made a partner in the firm in 1903, and succeeded as senior partner in 1913. He continued his father's pioneering and research work on steel rails and was the inventor of several processes for increasing their wear and resisting capacity, including the "sorbitic" process, which was also applied, during the war of 1914–18, to high-explosive shell forgings, whereby millions rejected, owing to defects, were rendered serviceable. This process was presented to the Government free of royalties. Another process, known as "in situ," prolonged the life of worn tramway rails at a time when relaying was impossible owing to the scarcity of steel and labour. For his services Mr. Sandberg was appointed a Commander of the Order of the British Empire. In 1928 he introduced the "oven" process for controlling the cooling of rails after manufacture, to avoid the fissuring which had been responsible for many diastrous failures and derailments, especially in America. He also acted as consulting and inspecting engineer to the Siamese and the Chinese State Railways and to many other British colonial and foreign railways.

He was a Commander of the Chinese Order of Chia Ho (3rd class), and of the Siamese Order of the White Elephant. A notable example of his ingenuity was the salvaging of about one million pounds' worth of coin and bullion from the S.S. *Egypt*, which had foundered off Ushant in 1922, and lay at a depth of 400 feet in the open sea. The undertaking occupied about 5 years and gave the world a new system of deep-sea salvage.

Mr. Sandberg was elected an Associate Member of The Institution on the 14th January, 1902, and was transferred to the class of Member on the 23rd April, 1918.

In 1903 he married Alexandra, third daughter of the late Mr. Alexander Staats Forbes, and had three sons and four daughters.

JOSEPH EDWARD WILLCOX was born at Radstock, Somerset, on the 16th January, 1857, and died at Edgbaston, Birmingham, on the 2nd February, 1941. He was educated at Wells Grammar School, privately, and at Bristol University College. He served his pupilage with Messrs. G. C. Ashmead and Sons, of Bristol, and in 1879 was appointed assistant to the late Mr. E. Pritchard, M. Inst. C.E., being engaged on water-supply and sewerage works. From 1881 to 1887 he acted as resident engineer on various water and sewerage schemes in the Midlands, and in 1887 was appointed Surveyor and Engineer to the Erdington Urban District Council. At the same time he started a private practice as a consultant, and in 1902, owing to the growth of this work, he relinquished his post and was appointed Consulting Engineer to the Council. His firm specialized in the design and construction of waterworks, sewerage, and sewage-disposal, and he was retained by the Birmingham Corporation to advise and report upon the provision of a third pipe-line from the Elan valley. He also had a wide experience as an expert witness before Parliamentary committees in connexion with numerous boundary and extension schemes, and advised many local authorities on problems of sewerage and sewage-disposal, including the treatment of tannery and milk wastes.

Mr. Willcox was elected an Associate Member of The Institution on the 6th February, 1883, and was transferred to the class of Member on the 19th December, 1905. He acted as Chairman of the Birmingham and District Association of The Institution in 1924. He was a Past-President of the Institution of Municipal and County Engineers and of the Institute of Sewage Purification.

In addition to his professional pursuits, he took an active interest in many public works in Birmingham. He was a Life Governor of Birmingham University and also served as Chairman of the Committee of the Birmingham General Hospital. For many years he was a director of the South Staffordshire Waterworks, and was also on the board of the Birmingham Crematorium.

He was unmarried.

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NOTE.—*Pages* [1] *to* [8] *can be omitted when the Journal is bound in volume form.*

NOTICES

No. 1, 1941—42

NOVEMBER, 1941

MEETINGS, SESSION 1941—42.

ORDINARY MEETING.

Arrangements have been made for the following Papers to be discussed on the date shown below :—

1941.	At the Inst. Mech. E.
Dec. 16 (Tues.) (2.30 p.m.)	*† "**Hammer-Blow in Locomotives : Can it not be Abolished Altogether?**" by Sir Harold N. Colam, B.A., M. Inst. C.E., and J. D. Watson, B.Sc. (Eng.), Assoc. M. Inst. C.E.,
	with
	*† "**Balance of Locomotive Reciprocating Parts**", by E. S. Cox, M. I. Mech. E.
	(Jointly with the Institution of Mechanical Engineers.)

JAMES FORREST LECTURE.

The James Forrest Lecture will be delivered at 2 o'clock on Tuesday, 13 January, 1942, by Dr. C. S. Myers, C.B.E., M.A., F.R.S., the subject being Psychology as applied to Engineering.

RAILWAY ENGINEERING SECTION.

1942.	
Jan. 27 (2 p.m.)	* Paper.—"**Permanent Way Tests and Practice on the L. M. & S. Railway,**" by W. K. Wallace, M.Inst.C.E.

SPECIAL ANNOUNCEMENTS.

SERVICE WITH THE ARMED FORCES.

A questionnaire regarding the present service of members and Students of The Institution with the Armed Forces accompanies this Number of the

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(*Advance proofs, for those who intend to be present, will be available about a fortnight before the Meeting, and copies may be obtained on application to the Secretary, Inst. C.E.)

†Abstracts of the Papers appeared on pp. 12, 13 of the October Journal.

Journal. It is hoped that the replies will enable The Institution to have the fullest information available when inquiries are received from Service and other Departments.

In this connexion it may be mentioned that the Committee on Skilled Men in the Services (under the chairmanship of Sir William Beveridge), set up by the Minister of Labour and National Service, has asked The Institution to assist in a survey, which the Committee is undertaking, with a view to obtaining information from any members of The Institution now serving in H.M. Forces, which will help to ensure that the best possible use is made of their technical qualifications and experience. The request for this information is being made with the knowledge of the Service authorities, and the details furnished will be welcomed by them.

Members and Students serving in Dominion Forces are particularly requested to complete and return the Form, in order that The Institution may have a comprehensive record of all its members and Students serving in H.M. Forces.

The main purpose of the questionnaire is to obtain general guidance as to the types of Units in which members and Students are serving; e.g. if in the Royal Engineers, whether in Field Companies, Works Services, Transportation, etc., or if in the Royal Artillery, whether in Surveys, Searchlights, and so forth.

ROYAL MARINE ENGINEERS.

Corporate Members who desire to be considered for Commissions, for which there are a limited number of vacancies, in the Royal Marine Engineers, a Corps engaged on Admiralty works ashore, should at once notify the Central Register of the Ministry of Labour and National Service, 41, Tothill Street, Westminster, S.W.1, quoting in their letters "Ref. E.264." Applicants should be between about 25 and 45 years of age and have had considerable site experience on actual constructional work—preferably on harbour work. The successful candidates will be graded according to their experience, either to the rank of Major, Captain or Lieutenant, but it should be appreciated that there are very few vacancies carrying the rank of Major.

ARMY OFFICERS' EMERGENCY RESERVE.

It is anticipated that the War Office may require gentlemen of between 31 and 40 years of age for the Works Services (Royal Engineers) at home and abroad, but it is not possible at this stage to give the number or the dates on which they will be needed.

These gentlemen, provided they are in reserved occupations, may be given direct commissions from civil life. After commissioning they will be given a short course in Military Duties and Works Services procedure.

Corporate members who wish to be considered for these Commissions should send their names to the Secretary of The Institution for transmission to the appropriate department of the War Office.

Particulars of a revised method of entry to the Royal Engineers for Associate Members between 25 and 31 years of age may be obtained from the Secretary of The Institution.

NATIONAL SERVICE (ARMED FORCES) ACT, 1939.

Students of The Institution who are above 18 years of age and who are liable for service under the National Service (Armed Forces) Act, 1939, must register at a Local Employment Exchange when their age-groups are called, and may obtain from the Secretary a form of certificate indicating their connexion with The Institution, which, upon production to the Registration Officer, will, it is anticipated, assist them in being posted to the ranks of the Corps of Royal Engineers or to a technical unit in which their qualifications can be employed.

MINISTRY OF LABOUR.

SCHEDULE OF RESERVED OCCUPATIONS.

The following entry appears in the Ministry of Labour's Schedule of Reserved Occupations :—

> Student engineering apprentice or learner—reserved at and above the age of 18 years.
>
> This entry relates only to a man employed in industry or under articles to a professional engineer who produces a certificate from a university or technical institution or from a professional Institution of Engineers to show that he is within two years of the satisfactory completion of a course of study with a view to offering himself for the first time for :—
>
> (i) an Engineering Degree ;
>
> (ii) an Engineering Higher National Certificate ;
>
> (iii) The Associate Membership Examination of the Institutions of Civil, Mechanical or Electrical Engineers, or the Associate Fellowship of the Royal Aeronautical Society ;
>
> (iv) An engineering examination of similar standing to those in (i), (ii) and (iii) above, e.g. the Associate Membership Examination of the Institutions of Marine, Mining and Structural Engineers, Testamur examination of the Institution of Municipal & County Engineers, Higher Grade Certificate in Gas Engineering.

In so far as The Institution of Civil Engineers is concerned, category (iii) applies to Students who are studying with a view to passing Sections A and B of the Associate Membership Examination within a period of 2 years, and who obtain from the Secretary of The Institution certificates to this

effect for production to the Registration Officer of the Local Employment Exchange when they register in their age-group under the National Service (Armed Forces) Act, 1939.

A Student who has not yet registered, but who wishes to apply for postponement of calling-up under this entry, must send to the Secretary of The Institution (in good time before the date upon which he is due to register in his age-group under the National Service (Armed Forces) Act, 1939) full particulars of his present occupation, together with documentary evidence in regard to the course of study he is pursuing for Sections A and B of the Associate Membership Examination and an indication of the dates upon which he intends to present himself for those Sections.

GENERAL ANNOUNCEMENTS.

THE JOURNAL.

The next Number of the Journal will be published on the 15th December.

AESTHETIC TREATMENT OF ENGINEERING STRUCTURES.

In response to a request for a pronouncement to be made, the Council wish to remind members that the aesthetic treatment of engineering structures falls within the scope of an Engineer's function.

MINISTRY OF HOME SECURITY, RESEARCH AND EXPERIMENTS BRANCH.

Copies of the following further Bulletins are now available to members, by permission of the Ministry of Home Security, upon application to the Secretary of The Institution. Application should be made by post card, quoting the Bulletin No. given in the left-hand column.

Bulletin No. C. 22. Automatic Devices for the Detection of Incendiary Bombs.

,, ,, C. 23. Technical Notes on the Structural Protection of Buildings against Incendiary Bombs.

ANGLO-SOVIET PUBLIC RELATIONS ASSOCIATION.

The Council have nominated Colonel J. R. Davidson, Member of Council, Professor A. J. Sutton Pippard, M.Inst.C.E., and Mr. E. Graham Clark, Secretary Inst.C.E., to serve on the Engineering Sub-Committee of the Executive Committee of the Anglo-Soviet Public Relations Association.

TRANSFERS AND ADMISSIONS.

On the 23rd September, 1941, the Council transferred fifteen Associate Members to the class of Members, and admitted sixty-one Students.

DEATHS AND RESIGNATIONS.

The Council have received, with regret, intimation of the following deaths and resignations :—

DEATHS.

BUCKLEY, Joseph William. (E. 1895. T. 1911.)	*Member.*
COURTNEY, Charles Frederick. (E. 1894.)	,,
DEACON, Maurice. (E. 1886. T. 1892.) (*former Member of Council.*)	,,
APTED, Frank Eardley. (E. 1906.)	*Associate Member.*
COLES, Eric Hatch, B.Eng. (E. 1939.)	,, ,,
SAVAGE, William. (E. 1895.)	,, ,,
WILLIAMS, Cecil Wrenne, B.A. (E. 1902.)	,, ,,
BALFOUR, George, M.P. (E. 1931.)	*Associate.*
*ARNOTT, John Woodrow. (A. 1936.)	*Student.*
*HECTOR, John Ross Monro, B.E. (A. 1937.)	,,
*WELLS, Ronald Stuart. (A. 1938.)	,,

RESIGNATIONS.

KING, James Foster, C.B.E. (E. 1910.)	*Member.*
GUEST, Alfred, B.Eng. (E. 1910.)	*Associate Member.*
TOHALL, Patrick, B.E. (E. 1922.)	,, ,,
MILLAR, William. (A. 1932.)	*Student.*
SHEPHERD, John Thompson. (A. 1939.)	,,

* On active service.

A SELECTIVE LIST OF RECENT ADDITIONS TO THE LIBRARY.

[Journals, Proceedings of Societies, etc., are not included.]

AIR DEFENCE. PRENTISS, *Lt.-Col.* A. M. "Civil Air Defence." 1941. McGraw-Hill. 15*s.*

DEEP DRAWING. *See* METALLURGY.

ELECTRO-MAGNETISM. ROTERS, H. C. "Electro-Magnetic Devices." 1941. Chapman and Hall. 36*s.*

INSULATION. MINER, D. F. "Insulation of Electrical Apparatus." 1941. McGraw-Hill. 35*s.*

LATHES. HILTON, B. R. "The Lathe Operator's Manual." 1941. Pitman. 6*s.*

MACHINE SHOPS. COLVIN, F. H., and STANLEY, F. A. "Running a Machine Shop." 1941. McGraw-Hill. 24*s.* 6*d.*

—— DURNEY, W. C. "Machine Shop Practice." 1941. Pitman. 7*s.* 6*d.*

METALLURGY. JEVONS, J. D. "Metallurgy of Deep Drawing and Pressing." 1940. Chapman and Hall. 50*s.*

METALS. CHALMERS, B., and QUARRELL, A. G. "Physical Examination of Metals. Vol. 2, Electrical Methods." 1941. Arnold. 20*s.*

MICROSCOPY. ALLEN, R. M. "The Microscope." 1940. Van Nostrand. 15*s.*

*PETROLEUM. DUNSTAN, *Dr.* A. E., and others. "The Science of Petroleum." 4 vols. 1938. Oxford Univ. Press. £15 15*s.*

SHIPS AND SHIPBUILDING. CARMICHAEL, A. W. "Practical Ship Production." 2nd ed. 1941. McGraw-Hill. 17s. 6d.

—— NEWTON, R. N. "Practical Construction of Warships." 1941. Longmans Green. 21s.

SOIL MECHANICS. KRYNINE, D. P. "Soil Mechanics." 1941. McGraw-Hill. 35s.

SOIL STABILIZATION. BROWN, V. J., and others. "Soil Stabilization after C. A. Hogentogler." 1939. Gillette Publ. Co. 12s.

WAR DAMAGE. WILLIAMS, H. B., and EVANS, M. "Law and Practice of War Damage Compensation." 1941. Heffer. 21s.

WARSHIPS. *See* SHIPS.

WELDING. DAVIES, A. C. "Science and Practice of Welding." 1941. Cambridge Univ. Press. 10s. 6d.

WORKS. MOLLOY, E., *Ed.* "Introduction to Works Practice." 1941. Newnes. 5s.

The foregoing books, with the exception of that marked with an * asterisk, may be borrowed from the Loan Library.

WAR DAMAGE ACT, 1941.

War Damage Commission,
Devonshire House,
Mayfair Place,
Piccadilly,
London, W.1.

WAR DAMAGE ACT, 1941.

Section 7.

The War Damage Commission hereby give notice that they have, for the purpose of giving effect to directions given by the Treasury under sub-section (1) of section 7 of the War Damage Act, 1941, and under the power conferred upon them by sub-section (2) of the said section, specified the following class of works for making good war damage :—

Works costing more than £1,000 or ten times the net annual value (if any) of the hereditament, whichever is the less, to be executed for making good the war damage sustained by any one hereditament situated within the following areas :—

(*a*) The County Boroughs of East Ham and West Ham, and that part of the County Borough of Portsmouth south of Ports-creek.

(*b*) The Boroughs of Crosby and Dover.

The War Damage Commission also give notice that they, under the power conferred upon them by the aforementioned sub-section, impose or

any person, who proposes to execute for making good war damage any works (other than temporary works) of the above specified class, an obligation to inform the War Damage Commission of the proposal, and thereafter to furnish to them such particulars of the proposed works as they may require in any particular case.

In this notice a "hereditament" means either a hereditament as appearing in the rating valuation list, or, in the case of a hereditament which is exempt from rating and does not appear in that list, the hereditament so exempted, provided that where there is more than one occupation of a single building, the hereditament shall be the building.

F. P. Robinson, *Secretary.*

26th September, 1941.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH.

The Building Research Station of the Department of Scientific and Industrial Research has issued, as a supplement to "Wartime Building Bulletin No. 15", a new Bulletin 15a *. This contains modifications to two of the factory designs given in No. 15, and two new factory types. One of the new types and the modifications to the existing types have been devised to help their camouflage treatment. The other new type, designed by the Directorate of Constructional Design, Ministry of Works and Buildings, is intended to save steel. A table is given showing the weights of steel used in various factory types. As usual, working drawings may be obtained price 2*s*. per sheet, post free, on application.

Wartime Building Bulletin No. 18, "Fire Stops for Timber Roofs," which has just been issued by the Building Research Station, describes simple structural devices that can be erected to check the spread of fire along roofs containing timber or other combustible material. In tests carried out at the Building Research Station on two small roofs the devices proved to be effective in stopping a fire, and it is believed that

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* "Wartime Building Bulletin No. 15a" (Supplement to Bulletin No. 15), published by H.M. Stationery Office, price 6*d*. net.

they would provide a useful check on large roofs. Work on the development of these fire stops was carried out at the instance of, and in collaboration with, the Fire Prevention Executive and the Ministry of Aircraft Production. Copies of the Bulletin may be obtained from H.M. Stationery Office, price 1*s*. net.

EDMUND GRAHAM CLARK, M.C., B.Sc., M. Inst. C.E.

SECRETARY OF THE INSTITUTION